Advanced Interferometric Surface Measurement in the Technology Frontier

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The addition of electronics, computers and software to interferometry has provided enormous improvements in the measurement of surface shape and roughness. This talk will describe some of these improvements and how they advanced the technology frontier.

1. Introduction

Improved computers, electronics, and software have helped make possible enormous improvements in the measurement of surface shape and surface roughness. These measurement enhancements have made possible enormous improvements in the fabrication of precision optics, hard disk drives, machine tools, and semiconductors. This talk will discuss six areas where interferometric measurement improvements have been made: 1) The use of computer generated holograms for the testing of aspheric optics, 2) phase-shifting interferometry, 3) two-wavelength interferometry, 4) vertical white-light scanning interferometry, 5) techniques for performing interferometric measurements more accurate than the reference surface, and 6) vibration insensitive interferometers.

2. Computer generated holograms (CGH)

The ability to use aspheric surfaces in optical systems has greatly improved the quality of optical systems. A major stumbling block in using aspheric surfaces is being able to test the aspheric surfaces. CGHs provide a good method for providing a known reference wavefront for testing aspheres.[1] The CGH can be thought of as a binary representation of the interferogram, or hologram that would be recorded if we were to interfere the aspheric wavefront coming from a perfect aspheric surface with the reference beam. The procedure for making the CGH is to first raytrace the interferometer to determine the position of the fringes in the theoretical interferogram that would be obtained if the mirror under test were perfect. A plotter, such as a laser beam recorder or an e-beam recorder, is then used to draw lines along the calculated fringe positions. Figure 1 shows a typical CGH.

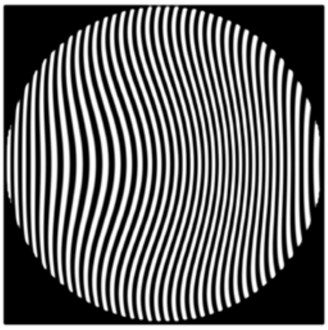

Figure 1. Typical CGH.

Using computer generated holograms to test aspheric optics is extremely useful because of the wide variation of asphericss that can be tested. Crosshairs can be put on the CGH to aid in the alignment of the CGH and additional holograms can be placed on the CGH to aid in the alignment of the optics or to aid in calibration of the CGH. Laser recorders and e-beam recorders have the resolution and accuracy required to make high quality CGHs for testing state-of-the-art aspheric elements. CGH interferometers work well with phase-shifting techniques.

3. Phase-Shifting Interferometry (PSI)

Most optical testing interferometers now use phase-shifting techniques because phase-shifting is a high accuracy rapid way of getting the interferogram information into the computer and the inherent noise in the data taking process is so low that in a good environment angstrom or sub-angstrom surface height measurements can be performed. In phase-shifting interferometry the phase difference between the interfering beams is changed at a constant rate as the detector is read out.[2, 3] It can be shown that by making three or more measurements of the irradiance of the interference pattern as the phase difference is varied, it is possible to accurately determine the phase difference between the two interfering beams. Once the phase is determined across the interference field, the corresponding height distribution on the test surface can be determined. Almost all interferometers used to measure surface height variations use phase-shifting techniques.

4. Two Wavelength Interferometry (TWI)

Sometimes visible wavelength interferometry has too much resolution to perform a measurement. Rather than going to long wavelength interferometry to reduce the sensitivity it can be more convenient to use two-wavelength interferometry. If the surface under test is measured using two wavelengths, λ_1 and λ_2, and the two measurements are subtracted, the resulting measurement is equivalent to a measurement performed using a longer wavelength given by

$$\lambda_{eq} = \frac{\lambda_1 \lambda_2}{|\lambda_1 - \lambda_2|}$$

By combining two-wavelength interferometry with phase-shifting interferometry it is possible to obtain the dynamic range of the equivalent wavelength and the precision of the single wavelength.[4]

5. Vertical White-Light Scanning Interferometry

While multiple-wavelength interferometry works well on many samples, sometimes if the surface is rough, noisy data points will cause errors in the measurements. Another approach for obtaining a large dynamic range interferometric measurement that will work with nearly any surface is to use vertical scanning interferometry. If a white light source is used in an interferometer the best contrast interference fringes are obtained only when the two paths in the interferometer are equal. Thus, if an interferometer is made such the path length of the sample arm of the interferometer is varied, the height variations across the sample can be determined by looking at the sample position for which the fringe contrast is a maximum. In this measurement there are no height ambiguities and since in a properly adjusted interferometer the sample is in focus when the maximum fringe contrast is obtained, there are no focus errors in the measurement of surface microstructure.

By using digital signal processing (DSP) hardware to demodulate the envelope of the fringe signal it is possible to produce fast, non-contact, true three-dimensional area measurements for both large steps and rough surfaces.[5, 6]

6. Performing Interferometric Measurements More Accurate than the Reference Surface

There are several techniques for performing measurements of flat surfaces, spherical surfaces, or surface roughness that are more accurate than the reference surface.[7, 8] All of these techniques require making multiple measurements while rotating or translating the surface under test and performing arithmetic calculations on the measured data. While these techniques have been available for many years, it is only due to the high precision of PSI that the techniques have become extremely useful for improving the ability to produce high quality optical surfaces.

7. Vibration Insensitive Interferometers

The measurement accuracy of PSI is generally limited by the environment. In PSI it is important to change the phase difference between the two interfering beams between intensity measurements in a controlled manner. This is where the environment becomes critical, because vibration or air turbulence can change the phase difference between the two beams in unknown ways and hence introduce large errors in the measurement. Techniques such as carrier frequency interferometry, closed-loop feedback vibration compensated interferometry, and single-shot phase-shifting interferometry can be used to reduce the effect of the environment.

A superior approach is to have all four phase-shifted frames fall on a single CCD camera as shown in Figure.2. In this arrangement, an interferometer is used where a polarization beamsplitter causes the reference and test beams to have orthogonal polarization. After the two orthogonally polarized beams are combined they pass through a holographic element that splits the beam into four separate beams resulting in four interferograms. These four beams pass through a birefringent mask that is placed just in front of a CCD camera. The four segments of the birefringent mask introduce phase shifts between the test and reference beams of 0, 90, 180, and 270 degrees. A polarizer with its transmission axis at 45 degrees to the direction of the polarization of the test and reference beams is placed after the phase masks just before the CCD array. Thus, all four phase-shifted interferograms are detected in a single shot on a single detector array.[9]

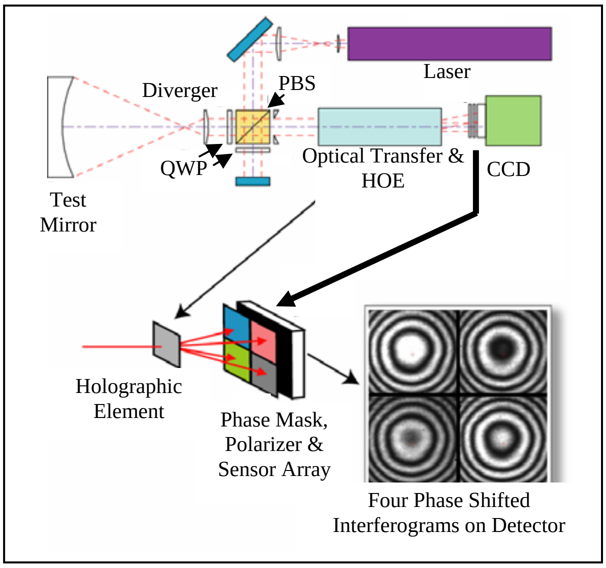

Figure 2. Single shot interferometer (PhaseCam)

By making short exposures the vibration, as well as the air turbulence is frozen. The effects of air turbulence can be reduced by taking many sets of data, where the time between the different data sets is long compared to the time it takes for the turbulence to change, and then averaging the data.

8. References

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