Developments in Optical Testing Technology During the Last Decade

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Abstract: Modern electronics, computers, and software have made it possible to greatly improve the testing of optical components and optical systems and the resulting improvements in the new optical instruments and devices we use are evident. Until recently a major limitation of interferometry for precision metrology was the sensitivity to the environment. In recent years many techniques for performing high quality interferometric measurements in non-ideal environments have been developed and new techniques are being introduced all the time. This talk discusses one very powerful technique for reducing the effects of vibration and atmospheric turbulence on interferometric measurements. The application of this technique for the measurement of surface vibration, the testing of optical components including large astronomical optics, the phasing of segmented optical components, and the measurement of deformations of diffuse structures will be described.
OCIS codes: 120.0120, 120.3180, 120.3940, 120.4290, 120.5050, 120.6650

1. Introduction

Phase-shifting interferometry is a powerful way of getting surface height data into a computer and it is extremely useful for the testing of optics, but in many situations, especially for the testing of large telescope optics, the measurement accuracy is limited by the environment and sometimes the environment is sufficiently bad that the measurement cannot be performed. During the past ten years there have been many advances using modern optics, electronics, and software to make it possible to perform precision interferometric measurements in the presence of vibration and turbulence. This paper describes some of these advances in reducing effects of vibration by using dynamic (single-shot) interferometry techniques. The single-shot interferometer described is insensitive to vibration and many measurements can be averaged to reduce the effects of air turbulence enabling the precision measurement of large optical components. The particular technique described will work with both long coherence and short coherence sources. The use of short coherence sources makes it possible to reduce coherence noise in interferometric measurements.

2. Simultaneous phase-shifting interferometer

In conventional phase-shifting interferometry 3 or more interferograms are obtained where the phase difference between the two interfering beams changes by 90-degrees between consecutive interferograms [1]. Vibration effects can be reduced if all the phase-shifted frames are taken simultaneously. While there are several ways of obtaining all the phase-shifted frames simultaneously, a technique that is especially useful because it works well with multiple wavelengths or white light involves the use of a quarter waveplate followed by linear polarizers at different angles. For this technique the phase shift between the two interfering beams is nearly independent of wavelength. The quarter waveplate is oriented to convert the test beam into left-handed circular polarization and the reference beam into right-handed circular polarization. It can be shown [2] that if these circularly polarized beams are transmitted through a linear polarizer a phase shift between the two interfering beams proportional to twice the rotation angle of the polarizer results.

Thus, if a phase mask is made of an array of 4 linear polarizer elements having their transmission axes at 0, 45, 90, and -45 degrees, where a polarizer element is placed over each detector element, the mask will produce an array of four 0, $\pi/2$, π, and $-\pi/2$ degrees phase shifted interferograms. This polarizer array can be used with both Twyman-Green and Fizeau interferometers.

Figure 1 shows a schematic of a Twyman-Green interferometer using the micropolarizer array. The essential properties of the two-beam interferometer are that the test and reference beams have orthogonal polarization and the size of the micropolarizer array matches the CCD array. This interferometer is especially useful for testing large concave astronomical mirrors where it is not practical to put both the interferometer and the mirror on a vibration isolated table. Also, by averaging several frames of data the effects of air turbulence can be minimized.

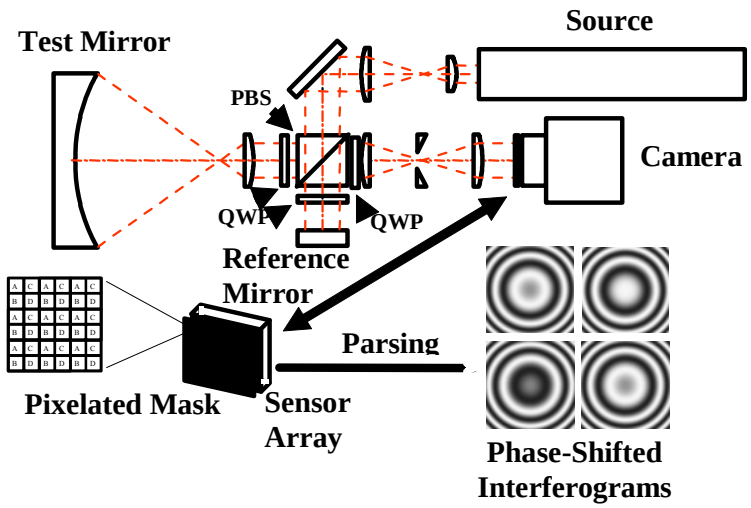

Fig. 1. Twyman-Green simultaneous phase-shifting interferometer configuration.

A single-shot laser-based Fizeau interferometer is more difficult to construct than a Twyman-Green interferometer because the Fizeau is more common path and it is hard to obtain a reference and test beam having orthogonal polarization. In principle, a quarter-wave plate can be placed between the test and reference surfaces to rotate the direction of polarization of the test beam by 90 degrees, but in practice this does not work well, especially for the testing of spherical optics. Techniques where the reference and test beams are tilted with respect to each other have been described, but a better approach is the on-axis approach shown below in Figure 2. [3].

In this interferometer, a short coherence light source is used. The source beam consists of two time delayed orthogonally polarized beams. The time delay (path difference) between the two beams is set equal to the path delay in the Fizeau cavity. The desired interference results from the long path source beam reflected off the reference surface and the short path length source beam reflected off the test surface. All beams are on-axis so off-axis aberrations are not a problem. Since both source beams are reflected off both test and reference surfaces and only the two path-length matched beams give interference the fringe contrast is reduced, but it is still more than adequate. Since a short coherence light source is used spurious fringes are greatly reduced. One source that works well is a modulated diode having a coherence length of approximately 300 microns.

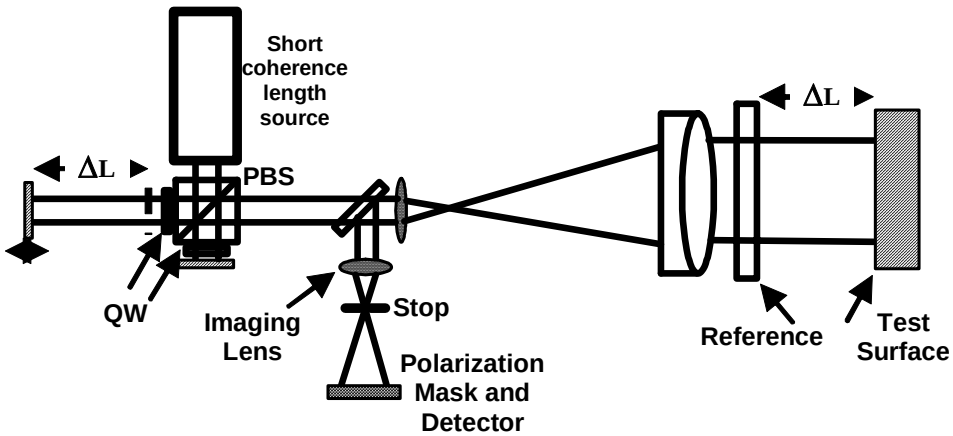

Fig. 2 Simultaneous phase-shifting Fizeau – short coherence length source.

This interferometer shown in Figure 2 is very good for testing windows having nearly parallel surfaces. If a long coherence source is used spurious fringes are obtained as shown in Figure 3, however with the short coherence

source interferometer spurious fringes are eliminated and by selecting ΔL, it is possible to look at the fringes for reflection off the first surface or the second surface.

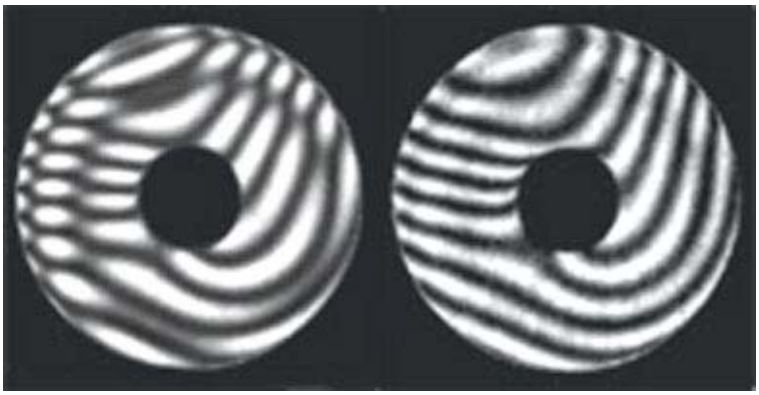

Fig. 3 Interference Fringes Obtain Testing a Thin Glass Plate.
a) Long coherence length source. b) Short coherence length source.

3. Conclusions

A single-shot interferometer can go a long way in reducing the effects of what is often the largest source of error in phase-shifting interferometry, namely vibration and interferometry can be used in many more applications. Averaging many frames of data obtained using a single-shot interferometer can reduce errors due to air turbulence. Averaging data frames in the presence of vibration will average out the double frequency errors common in phase-shifting interferometry and generally more accurate results can be obtained in the presence of vibration than can normally be obtained using conventional temporal phase-shifting interferometry in the absence of vibration. Also, it is possible to measure a vibrating surface to determine precisely how the surface is vibrating and movies can be made showing how the vibrating surface shape changes. Once a person works with a simultaneous phase-shifting interferometer it is hard to go back to working with a temporal phase-shifting interferometer.

4. References

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