Dynamic Interferometry for On-Machine Metrology

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Abstract: A compact, vibration insensitive interferometer design that is well suited for measuring optics while mounted in-situ on polishing equipment is presented. The system employs a single frame phase sensor that permits acquisition in tens of microseconds to mitigate the effects of vibration or relative motion with the test part. The theory of operation is presented along with experimental test results, which characterize repeatability and precision under static and high-vibration conditions.
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1 Introduction

Recent advancements in localized polishing methods allow rapid fabrication of large optics through the use of a measurement feedback loop [1,2]. A laser interferometer is used to measure the surface shape of the unfinished optic, the results are compared against the desired profile, and a difference map is produced for further polishing. To save time and cost it is desirable to measure the surface "on-machine" where the interferometer is integrated into the same polishing machine, either through a tower arrangement or by directly coupling the interferometer to the polishing spindle. In these applications it is necessary to employ compact interferometers that are insensitive to vibration and motion known as "dynamic interferometers."

In addition, modern techniques can polish relatively high spatial frequency components directly into the optical surface. Because of this, it has become imperative to reduce coherent noise, which is intrinsic to laser interferometer measurement systems. Without the noise reduction, coherent artifacts will print-through into the measured surface and will be polished into the optic. Thus, the need exists for a dynamic interferometer with very low coherent noise.

In this paper, a compact dynamic, single-frame acquisition, interferometer that addresses the needs of in-situ measurements for localized polishing methods and an option for coherent noise reduction using an extended source is presented. First, the interferometer and phase-shifting techniques will be discussed, then the extended source will be reviewed and finally experimental results will be presented.

2 Dynamic Interferometer Description

The Dynamic interferometer system consists of a Twyman-Green arrangement, a pixelated phase-mask that allows single shot dynamic measurements to be made [3], and an external fiber coupled HeNe Laser. The Tywman-Green configuration and the external laser source result in a very compact design. The dimensions of the interferometer head are 18cm x 16cm x 9cm. Small enough to fit in the most challenging of test configurations. The pixilated phase-mask provides the means capturing the phase-shifted data in tens of microseconds.

3 Phase-Shifting Techniques

The heart of the measurement system lies in a pixelated phase-mask where each pixel has a unique phase-shift [3]. The overall concept consists of a polarization interferometer that generates a reference wavefront and a test wavefront having orthogonal polarization states (which can be linear as well as circular) with respect to each other; a pixelated phase-mask that introduces an effective phase-delay between the reference and test wavefronts at each pixel and subsequently interferes the transmitted light; and a detector array that converts the optical intensity sensed at each pixel to an electrical charge. The pixelated phase-mask and the detector array may be located in substantially the same image plane, or positioned in conjugate image planes.

In principle, a phase-mask could be constructed using an etched birefringent plate, however, such a device is difficult to manufacture accurately. An alternative approach is to use an array of micropolarizers. Kothiyal and Delisle [4] showed that when analyzing two orthogonally circularly polarized beams with a polarizer, the phase-shift between the beams is a function of the orientation of the polarizer. Thus by arranging the micropolarizers at different angels the requisite phase-shifts are produced.

4 Noise Reduction

Noise is caused in the interferometer due to spurious reflections from optics within the system interfering with both the reference and test beams. The reflections can be caused either by coatings or defects on the optical surfaces. Utilizing a spatially extended source rather than a point source will suppress the interference between all surfaces except the reference and test surfaces due to the fact that a shear exists between the spurious beam and the reference and test beam. In general, the larger the extended source, the higher the noise suppression, however, the contrast of the desired interference pattern may be reduced as a consequence. The Twyman-Green interferometer has the advantage of allowing the test and reference mirrors to be placed in conjugate planes so that, in principle, a very large spatially extended source can be utilized. In practice it is desirable to have a finite working range to allow for different test setups.

To understand how an extended source can be effective in reducing the coherent noise in a coherent imaging system, it is useful to review the Van Cittert-Zernike theorem. The Van Cittert-Zernike theorem states that for quasi-monochromatic light the degree of coherence between two offset points is equal to the absolute value of the normalized Fourier transform of the intensity distribution of the source [5,6].

From the Van Cittert-Zernike theorem it is easy to imagine that for a sufficiently extended source the coherence of laterally offset points can be significantly reduced minimizing the opportunities for stray reflections and diffracted beam to interfere. The reduction in coherent noise afforded by an extended source has been investigated by many authors [7,8].

5 Conclusion

There are three important characteristics for interferometric on-machine metrology; the system must be vibration insensitive or “dynamic”, the interferometer head must be compact for ease of mounting in tight spaces and the coherent noise must be kept to a minimum to avoid polishing unwanted artifacts into the surface when using localized polishing techniques. In this paper, a compact, dynamic single-frame acquisition, interferometer that addresses these needs and an option for coherent noise reduction using an extended source was presented.

6 References

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