The Instrument Transfer Function
INTRODUCTION

Precision imaging, lithography, and X-ray applications require optics that perform at an extremely high level. In addition to strict form error specifications, the optics for these applications often require critical control of mid-spatial frequency content surface characteristics. This is critical to reduce light scattering and improve optical efficiency for extreme performance applications.

An interferometer is a common instrument for characterizing optical surfaces to very high precision that can be applied with care to enable extremely low uncertainty measurements to address stringent metrology requirements. However, to quantify mid-spatial frequency content, it is not enough to simply apply any interferometer in a more precise manner because most do not have sufficient lateral resolution. Interferometer design must keep up with these requirements to enable metrology that can clearly “see” mid-spatial frequency content.

Interferometers are most accurate at qualifying low spatial frequencies that correspond to the overall form error of the object surface. The instrument’s response begins to decline as spatial frequencies become higher, resulting in height information in the measurement being attenuated relative to its actual height as spatial frequency increases. This is analogous to any imaging system that begins to lose contrast as surface details become finer. At the point when the spatial frequency is beyond the resolution limits of the instrument, the response falls to zero.

THE INSTRUMENT TRANSFER FUNCTION

The ability of an interferometer to quantify mid-spatial frequency content is defined not only by its sampling density (camera resolution), but also by the many critical design aspects of the optical illumination and imaging system. The instrument transfer function (ITF) quantitatively characterizes the response of the instrument as a function of spatial frequency. Analogous to the MTF of an intensity imaging system that uses an intensity impulse (light/dark intensity step), ITF quantifies the spatial frequency response of an interferometer using a phase impulse (physical step).

A physical step contains infinite spatial frequency, so it is an ideal phase impulse if its transition is small relative to the resolution of the interferometer (<< 1 pixel). Since an interferometer will attenuate spatial frequency information, the measured step will contain something less than infinite spatial frequency. The amount of attenuation of spatial frequency content of the measured step accurately describes the ITF of an interferometer. The output of such a qualification is normalized ITF as a function of spatial frequency over the band which the instrument can measure. It is convenient to represent spatial frequency as a function of the number of cycles per aperture, since interferometer aperture sizes vary.

Figure 1 shows an ITF curve for a very high-resolution interferometer. The greater the area under the ITF curve, the better the instrument will be at characterizing mid and high spatial frequencies. In this case, the interferometer has an ITF > 0.6 at 1,000 cycles per aperture. This qualification was made of an interferometer with a 4-inch aperture, so it is capable of qualifying features that are up to 10 cycles/mm (0.1 mm physical size) at >60% of their true height.

A practical method for performing an ITF qualification of an interferometer is by measuring an artifact with precision step features. An interferometer can have a response that varies as a function of position and orientation of features, so it is important that step features cover the entire aperture in multiple orientations. A method developed by ZYGO utilizes a proprietary step artifact (Figure 2) with precise lithographically

Figure 1: Typical interferometer ITF as a function of cycles per aperture

Figure 2: ZYGO ITF step artifact diagram
produced step edges (Figure 3) in the vertical and horizontal orientations that extend to the edge of the aperture. An integrated software package automatically locates the measured step features and analyzes them in thousands of locations along each step.

**SELECTING AN INTERFEROMETER**

Figure 4 shows the measurement of an ITF step artifact, that is used to quickly and quantitatively characterize the spatial frequency response of an interferometer. The advantage of using the ITF to describe interferometer lateral resolution is that it is a single function that defines the entire system’s capability as a function of all spatial frequencies, rather than relying only on a specification like a camera resolution. Even worse would be a qualitative visual inspection of a test target illuminated by incoherent light — an imaging evaluation that is inconsistent with the design goals of laser-based, phase shifting interferometers.

High precision mid-spatial frequency metrology is enabled by other critical capabilities that should be considered when selecting an interferometer. The laser source of any interferometer is the heart of the system. A typical source is a HeNe laser operating at 632.8 nm, where important factors to consider are laser power and specified level of frequency stabilization.

Vibration is a common problem with high precision measurements when an ideal environment is not available. Acquisition techniques that enable metrology in the presence of vibrations, while also maintaining the highest precision on-axis cavity configuration, are highly beneficial as well.

In the most extreme environments, acquisition techniques are available that are insensitive to vibration while still enabling precision metrology where it would not otherwise be possible. These patented dynamic acquisition techniques have proven to provide surface metrology that is equivalent to traditional phase shifting interferometry.

The Verifire™ HDX interferometer recently introduced by ZYGO possesses the highest ITF capability on the market today, enabled by a 3.4k x 3.4k pixel (11.6 Megapixel) camera and rigorously designed optical system to achieve high ITF over the full aperture. It is capable of qualifying mid-spatial frequency content of high performance optics in the most demanding applications that modern optics are addressing, and is equipped with the ZYGO-made HeNe laser source, as well as proprietary QPSI™ vibration robust acquisition and DynaPhase™ vibration insensitive acquisition.

Laser interferometers from Zygo Corporation were first introduced commercially 45 years ago. Today, ZYGO continues to maintain the leadership role in surface form metrology using laser interferometry. Thousands of ZYGO interferometers are installed worldwide and relied upon daily to provide accurate production measurements of optical components and assemblies.