Absolute measurement

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Introduction

APPLICATION NOTE

Absolute measurement – Why is it important and how do you know if your wavefront sensor is capable?

A lot of wavefront sensor manufacturers claim that their devices are capable of absolute measurement. In order to better help you to understand what this means, the best place to start is with a straightforward definition of the words that comprise that term.

Merriam Webster's dictionary defines absolute (in this case) as "free from imperfection or fault" and measure as "an adequate, given or fitting amount or degree; commensurate or due to proportion." Even though these definitions may seem somewhat oxymoronic, when we put them into the context of wavefront analysis, we can provide a reasonably accurate definition by saying "the ability to provide the most accurate, quantitative and objective data possible on the optical qualities of a light source without relying on a similar external reference in order to establish a proportional relationship."

The importance of absolute measurement versus relative measurement depends of course on your application.

At Imagine Optic, we believe that any application is better served by the ability to perform absolute measurement, even if the final result is based on relative measurement. Why? Because it provides an objective point of reference for decision making.

What's the interest in true absolute measurement? The answers are as simple to provide as the technique is difficult to master:

- complete measurement and characterization of laser beams, laser diodes and LED's
- measurement of the optical assembly or system with its source (auto-collimating lenses, collimators, laser assemblies...)
- adjustment and characterization of optical systems as well as the adjustment of collimators, afocal optical elements, zoom assemblies and other components in order to measure the focal spot, the aberrations at the center of the field and the Modulation Transfer Function (MTF)
- easier construction and lower costs (often associated with buying components that finally prove unnecessary)
- adaptive optics without a reference beam

Achieving absolute measurement over a wide dynamic range is a challenge that few manage to overcome. Many manufacturers are unclear as to their devices' capacities or, in the rare cases where detailed information is provided, the dynamic and wavelength ranges are not specified. These same providers prefer to insist on the sensitivity, the repeatability or the precision of measurements in relative measurement mode. All of these terms mean the same thing – the ability of the device to measure minute variations in the wavefront's phase in relation to known data. Plainly stated, this does not apply to the device's ability to measure the beam's phase in relation to the form of its own true wavefront. Only Imagine Optic provides written proof of our HASO wavefront sensors' dynamic range and wavelength range in absolute measurement mode.

HASO incorporates over ten years of industry leading excellence to overcome the limitations imposed on other devices. The secret is in the quality of the individual components at the heart of each HASO sensor and the mastery of the entire manufacturing process from design to delivery. Every HASO sensor incorporates:

1. optical elements of exceptional quality along the sensor's entire assembly
    - Imagine Optic is one of a small handful of manufactures to produce its own microlens arrays. In order to precisely measure the wavefront's local slopes over a wide dynamic and spectral range, our microlens arrays are composed of an exceptionally high optical quality material that ensures irreproachable focalization of each elementary beam (spot) on the detection grid. Other manufacturers rely on third parties for their arrays or may use opaque mask structures (Hartmann screens and shearing interferometers) that can cause a loss of wavefront data when the wavefront passes through.
2. a high-quality detector array (usually a CCD camera) that provides a homogeneous, pixel by pixel wavefront acquisition that ensures linearity and sensitivity
3. optimized design and meticulous assembly to guarantee accurate sampling and to eliminate the effects of outside interference
4. an powerful software interface that combines wide-ranging functionality with ease-of-use

Overcoming variations in beam intensity

One of the keys to performing true absolute measurement is the ability to compensate for the effect that extreme variations in your beam's intensity can have on the wavefront sensor's interpretation of its phase. Even if all of the above criteria are met beyond reproach and to varying degrees, all wavefront sensors are sensitive to the effects of heterogeneous intensity distribution in the measurement pupil on phase aberration measurement. Although Hartmann wavefront sensors and shearing or point-source diffraction interferometers are particularly sensitive to this malignant effect on measurement, Shack-Hartmann sensors equally, even if to a lesser extent, fall victim as well.

To counter this effect and provide accurate measurements, HASO wavefront sensors employ patented independent and simultaneous measurement of phase and intensity coupled with proprietary software correction algorithms. The combination of these with our other proprietary and patented technologies enables you to perform truly absolute measurements over the widest dynamic and spectral range available on the market.

How do you know if you sensor really performs absolute measurement?

As the title of this technology note indicates, we are going to show you how to test yourself the performance of your wavefront sensor. The procedure is actually quite simple and requires little time or preparation.

1. Place an intermittent source on a translation stage orthogonally in front of your sensor (in any range close enough for the wavefront to be measured) and set your sensor to measure in absolute mode
    a. Ideally, the source is a mono-mode, fibered laser or laser diode. In this case, the generated wavefront is spherical and nearly perfect, thereby ideal to test the sensor's performance
    b. In the absence of a fibered source, a non-fibered laser diode or LED with a flat window (avoid LED's with lenses) can be used. In this case, place the source in such a way that it is far enough away from the sensor to allow for only a small part of the wavefront, spherical and nearly aberration-free, to be detected. If you use an LED, please ensure that the casing does not reflect light from the emission zone. You can suppress parasite reflections by using a diaphragm that will mask errant light from the reflective LED casing.
2. Your sensor should measure a spherical wavefront, free from aberrations
3. Next, begin to move your source in order to vary, in a known manner, its position. During the translation, verify that the wavefront remains spherical and without aberrations, even when the tilt evolves, and that the value of the tilt measured by the sensor is coherent with the undergone translation.

This test shows how the aberrations measured by the sensor, from either a fixed source or one during translation, are in and of themselves an excellent indicator of the sensor's quality. In short, this simple test enables anyone to prove that a perfect spherical wavefront is measured as such by the sensor. You can equally perform the same test during collinear translation and observe the variations in the curvature of the measured beam.

Figure 2 shows the results obtained using a HASO3 wavefront sensor (setup is illustrated in Figure 1).

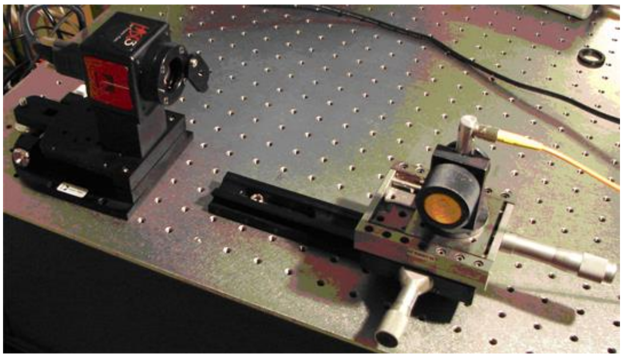

Figure 1. Wavefront measurement setup.

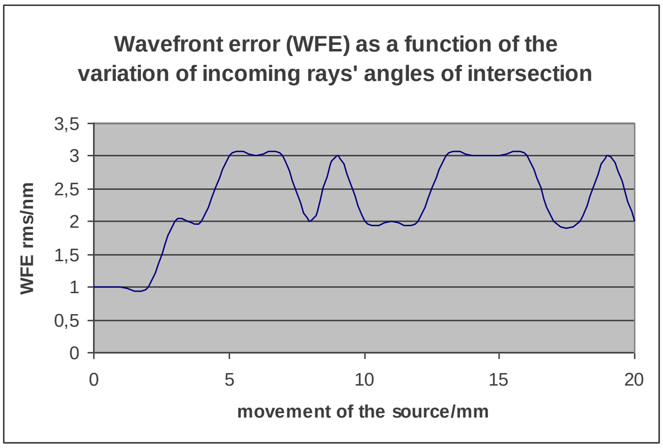

Figure 2. Wavefront error as a function of variation of incoming rays angles of intersection. X-tilt measurement error: 1.9 µrad rms; Y-tilt measurement error: 2.5 µrad rms; Linearity error: 0.09%; Wavefront quality: better than λ/100 rms.

Another simple manner to validate the absolute measurement capacities of your sensor is to compare the calculated Point Spread Function (PSF), obtained through calculations of the phase and intensity measurements (most wavefront sensors offer this feature), to that of a directly measured PSF, obtained by placing a camera in the beam's focal plane (see Figure 3)

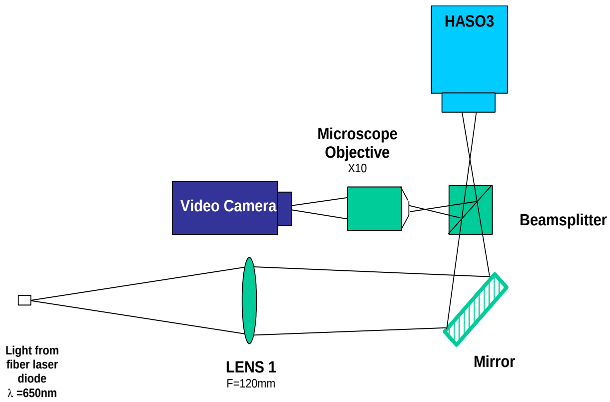

Figure 3. Setup to directly measure both wavefront and PSF (Point Spred Function).

If the wavefront's phase and intensity measurements are reliable, then your calculated PSF should be identical to the directly measured PSF.

As one could see from Figure 4, viewing the results of this test with your HASO wavefront sensor on your own is not difficult.

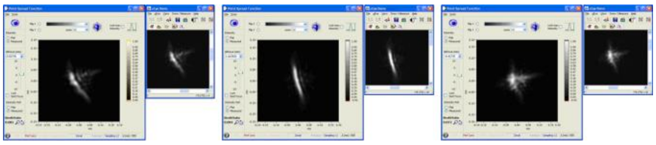

Figure 4. Calculated PSF (larger, left-hand screen capture) and directly measured PSF (smaller, right-hand screen capture).

Looking of three 3 screen captures (Figure 4), taken from actual wavefront measurements performed using HASOv3, one can clearly see that the calculated PSF (larger, left-hand screen capture) is identical to the directly measured PSF (smaller, right-hand screen capture).

Only Imagine Optic offers live demonstrations of absolute measurement. If you would like to see it yourself, please visit us at conferences and tradeshows indicated in the "news and events" sections of our website www.imagine-optic.com