Using HASO to compliment a beam profiler

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APPLICATION NOTE

HASO wavefront sensors – the ideal companion for your beam profiler

Customers that work with lasers know how important it is to have a properly aligned optical system to optimize the efficiency of their beam. In this technology note, we will explain why HASO Shack-Hartmann wavefront sensors are an ideal complement to your beam profiler.

Beam profilers are excellent, inexpensive tools for measuring the intensity of your laser at a very high spatial resolution. While they are extremely useful, the fact that they only measure intensity means that the data you rely on to perfect your beam is limited to the consequences of its imperfections rather than the causes behind them.

In contrast to beam profilers, HASO wavefront sensors use a wealth of patented technologies to measure your beam's phase and intensity, simultaneously and independently. This functionality, unique to HASO, provides you with information on the beam's geometric parameters and propagation as well as on the perturbations it's undergone.

The data you acquire allows you to understand the beam's evolution over time and space, and to determine where the problem is in your assembly in order to correct it quickly.

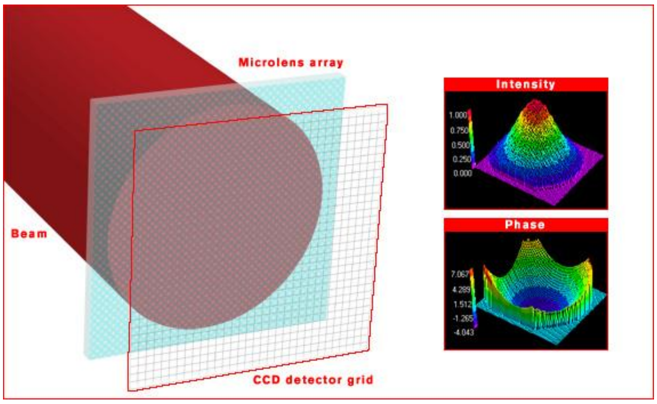

Figure 1. HASO's Shack-Hartmann technology provides information both beam intensity and phase.

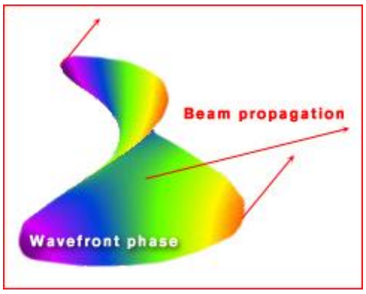

Figure 2. Here is shown how the rays that make up your beam propagate orthogonally in relation to the beam's phase. This allows you to understand its history, including geometric parameters and the perturbations it's undergone, as well as to determine its future evolution.

When you rely solely on the measurements furnished by a beam profiler, you can find yourself with a lot of guess work in order to get your beam up to peak performance, transforming what may often be a rapid correction into a long and arduous procedure. What is more, when you only measure intensity, you are never 100% sure that you have gotten your beam up to its full potential.

While, as we said, beam profilers are excellent tools, the inherent limitations of their technology also limit their effectiveness. In situations where speed and precision are absolute necessities, a beam profiler alone may not be sufficient to get the job done. One of the HASO family's many advantages is that it can be used in conjunction with your beam profiler, or in its place, allowing you to decide for yourself how you want to work.

More about measuring phase and intensity

While optimizing the intensity of your beam at a given point in space is the goal, measuring its phase in parallel lets you perform the adjustments necessary to achieve that objective. As we mentioned earlier in this note, measuring the phase and in intensity together provides you information on your beams geometric parameters and propagation through space and time (see Figure 3).

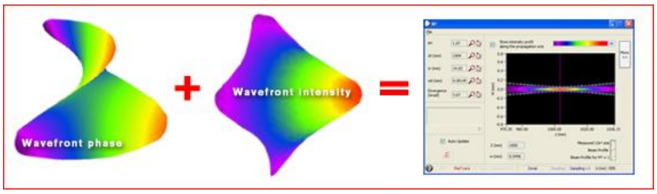

Figure 3. By combining the independent measurements of the beam's phase and intensity, HASO determines its M² parameter. This allows you to determine the beam's form anywhere in space, the position and shape of its waist, its divergence over distance, and its angular size.

<u>What makes HASO wavefront sensors unique and what does that mean to you?</u>

Imagine Optic's HASO wavefront sensors are based on the Shack-Hartmann technique for wavefront sensing (to learn more about this technology, please see the introduction and related documents on www.imagine-optic.com). The HASO family of products provides several key advantages over other Shack-Hartmann technologies.

Simultaneous and independent measurement of phase and intensity – HASO wavefront sensors use patented technology to provide the unique ability to measure both the phase and the intensity simultaneously yet independently. Used with its companion software, HASOv3, these synchronized measurements allow you to calculate the beam form anywhere over space and time, providing you not only with information on the beam's aberrations but equally on the cause of those abnormalities. This can help save your time when correcting the alignment of optics.

Absolute measurement – Another of HASO's patented technologies is its factory calibration process that eliminates the need for a reference beam. This allows you to compare your beam's performance to its own proper potential rather than that of an "ideal" reference beam.

This is accomplished through the exceptional optical quality and ultra-precise placement of the microlens array in relation to the detector plane (CCD camera). HASO sensors, depending on the model, can be calibrated to measure wavefronts at wavelengths between X-EUV (30 eV - 300 eV (4 nm - 40 nm)) through NIR (Near Infrared 1500-1600nm) and everything in between. While measuring in the calibrated range is highly recommended, HASO wavefront sensors are capable of measuring outside of their factory calibrated range.

High accuracy and wide dynamic range – HASO wavefront sensors' unique design enables them to offer the widest dynamic range available without compromising on accuracy. Combined with other key features including their achromaticity and insensitivity to vibration, HASO enables you to measure and correct highly aberrated, convergent or divergent beams quickly and precisely.

Part of the secret behind HASO's performance is the quality of Imagine Optic's microlenses and the fact that the microlens assembly is comprised of an exceptionally high quality optical medium with the microlens' convex surface facing the CCD detection grid. Products that rely on masking techniques (Hartmann or shearing interferometers) inherently lose data due to the mask's solid support structure.

Using HASO functionality for beam analysis and adjustment

HASO wavefront sensors, delivered with our HASOv3 software, provide you with all the tools you need to perform a variety of measurement and analysis procedures. Earlier in this document, we discussed the key advantages that the HASO family of products offers over other technologies. In this part of this note, we'll show you how HASO's superior design comes into play for beam analysis applications.

<u>General information on HASO wavefront sensors</u>

Our HASO products enable you to measure over a dynamic range from 4 to 1700nm[1] with exceptional accuracy ranging from λ/100 up to λ/1000[1]. HASO equally provides remarkable precision with intrinsic lateral resolutions ranging from 105 μm to 450 μm[1] and spatial resolutions from 256 up to more than 16,000 measurement points[1] with 12-bit resolution. And, HASO lets you work fast with speeds up to 1 kHz[1].

Analyzing and adjusting phase and intensity

As we discussed earlier, HASO wavefront sensors, used in conjunction with HASOv3 wavefront analysis software, allow you to measure your beam's phase and intensity simultaneously and independently. The data you acquire is not affected by severe variations in your beam's intensity that can provoke other technologies into providing false measurements. In short, performing both measurements at the same time, yet keeping them independent, provides you with precise information on the state of your beam that you can use in a variety of ways.

First, you can compare your beam's actual wavefront intensity and phase versus its best theoretical performance. This can help you work better and to save time by deciding for yourself what the optimal beam quality is to meet your individual needs. HASO equally allows you to analyze your beam's performance over time to identify progressive or evolutionary variations via a recurring measurement functionality that allows you to define measurement intervals from fractions of seconds to several minutes or hours. Examples include precise measurement of the thermal focus, or the optimization of the position and performance of lenses and mirrors in the laser chain as well as beam expanders and collimators.

Next, for those who work with beam amplification, HASO's independent measurement of phase and intensity can help avoid losses in amplification or the formation of unexpected hotspots by helping you to identify where the problem is in your assembly. Not only can this save you time but it can equally help you to protect sensitive optical components.

Improving beam quality

Our HASO products provide you with advanced software tools that take full advantage of the sophisticated hardware technology in our wavefront sensors.

PSF (Point Spread Function) and Strehl ratio

The PSF, or far field, is the spatial dispersion of the energy in the laser's focal plane. It is calculated by combining the phase and intensity measurements on the sensor's surface via propagation of the electromagnetic field in accordance with the law of free space propagation.

The PSF module also provides the Strehl ratio, allowing you to compare the actual maximum intensity on the focal plane to a perfect theoretical distribution of intensity without the presence of aberrations, avoiding the need for a beam profiler and going beyond the capabilities of interferometers.

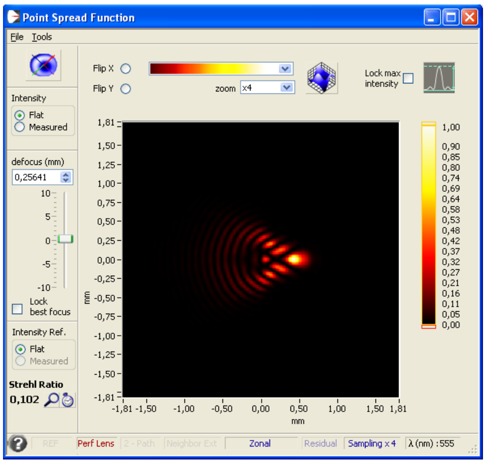

Figure 4. Example of PSF calculation

M² parameter

The M² parameter, M² calculation is accomplished by calculating the propagation of the electromagnetic field on different planes and reconstructing the envelope of propagation.

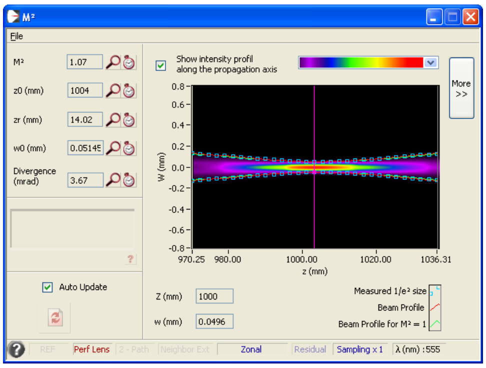

Figure 5. Example of M² calculation

A product of the phase measurement, the M² enables you to verify the position and quality of the beam's waist, to check the alignment and quality of focusing optics, to analyze the divergence of the beam as a whole or in any given direction, and to judge your beam's overall performance. HASOv3 equally offers a zoom function that allows you to magnify the displayed graphics to examine them in detail.

Zonal and modal reconstruction modes

HASOv3 also offers you the choice of choosing between zonal and modal wavefront reconstruction. This feature allows you to put the information on your beam to a variety of uses.

Zonal reconstruction is ideal for measuring and adjusting your beam because it allows you to analyze your beam's brut performance no matter what shape its pupil takes. HASOv3 reconstructs your beam's pupil using data acquired only from measurement points that receive a signal, whereas inferior products may present zones with no signal as aberrations.

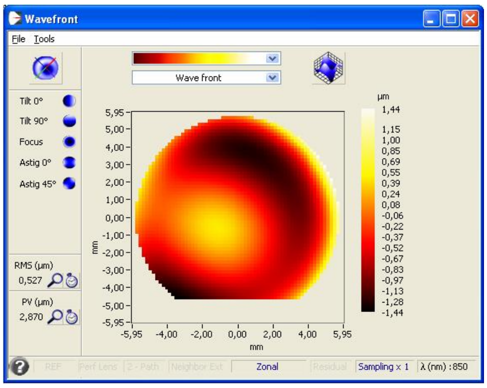

Figure 6. Zonal pupil reconstruction.

Modal reconstruction allows you to quantify aberrations in your beam and compare it to known polynomials via a software simulation interface. This mode is ideal for exporting data for reports and publications and only HASOv3 incorporates certain unique features into its circumscribed or inscribed pupil definition options.

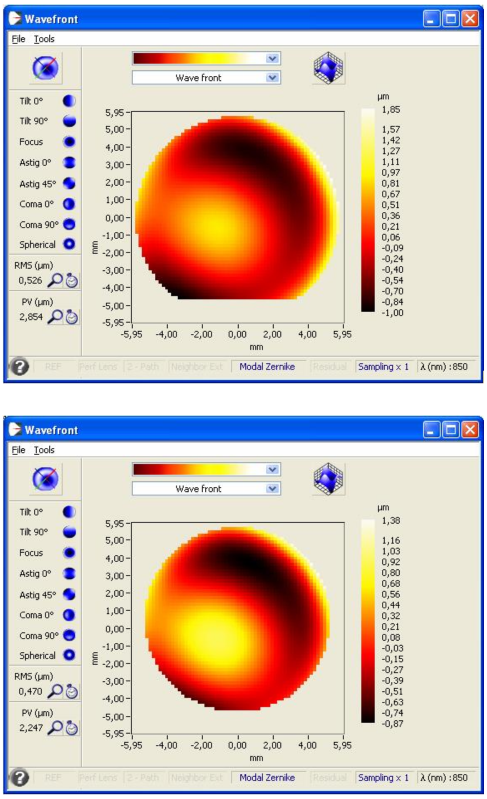

Figure 7. Modal pupil reconstruction for in real-time circumscribed (upper image) or inscribed (lower image).

When you choose to work with a circumscribed pupil, HASOv3 provides the unique, real-time (Figure 1 upper image) ability to detect the radius around your beam's entire pupil and, by eliminating measurement points with no signal, provides you with its true form. When you choose to work with an inscribed pupil, HASOv3 allows you to define both the measurement diameter and the area of your beam's pupil to be analyzed. Once again, only truly acquired data is represented.

In short, if there's nothing to measure, HASOv3 never provides false measurements by filling in the blanks with assumed data. Even more, in both zonal and modal modes, HASOv3 eliminates the corona around the pupil that can cause other products to furnish false measurements.

Convenience and ease of use – HASOv3 offers some other unique features that help you to facilitate your workflow including:

- Follow-up tools – historical data on tilts for directional stability, on focus for tracking targeting on the focal plane, on thermal stability and on mechanical details
- Screen zoom feature – This feature allows you to enlarge the display of your HASOv3 control panel so that you can easily see your monitor while you're working on various optical components that may be located at some distance from your screen.
- Remote operation – HASO can be controlled remotely over Ethernet and WiFi networks
- Save to video – record your acquisition sequences as video for use in presentations
- Reporting – simply define your report format and print in one click

As you can see, HASO offers a wide range of features specifically tailored to the needs of professionals working with lasers in a variety of domains. At Imagine Optic, we continuously strive to improve our products by maintaining a constant dialogue with our customers.

For every application, there's a HASO to respond to your needs. For example, HASO3 32 is an economic choice for characterizing and aligning beams with few imperfections, 128 GE is perfect for fine tuning, and HASO4 first (with a Single wavelength calibration (±50 nm)) or a unique HASO4 Broadband (with Full spectral range calibration over 400nm - 1100 nm) are ideal for precision measurement in spectral ranges between 400 and 800 nm or 532 and 1064 nm (YAG and frequency doubled YAG lasers).

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.

To find the nearest to you office or distibuter, please visite our contact page: http://www.imagine-optic.com/en/footer/imagine-optic/contact-us/

[1] - depending on the model and configuration