



Industrial quality control – HASO for ensuring the quality of NIR optical components

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APPLICATION NOTE

In the sector of industrial detection, the ability to mass-produce reliable, high-quality optical components is synonymous with maintaining competitiveness. Today's motion sensors integrate multiple optical elements into complex arrays. Making sure that components are compliant with factory specifications before they are integrated into final products is not only an effective means of cutting costs by reducing waste, but is equally important for ensuring ongoing customer satisfaction.

B.E.A., located in Liège and part of the HALMA group, designs, produces and markets a variety of remote presence and motion detection products for pedestrian, industrial and mass transit applications. A number of their products incorporate plastic lenses and mirrors optimized for the near-infrared (NIR - <1000 nm) spectrum produced by third-party manufacturers. B.E.A.'s reputation for excellence places severe requirements on the quality of the lenses provided by subcontractors. For their products, the necessary quality of integrated optical components approaches the limits of what is technically feasible in the mass-production of injection-moulded plastic lenses

One of the key monitoring points for B.E.A. is the ability to precisely control the optical parameters of delivered lenses, lenses that have a particularly strong numerical aperture (NA).

In addition, in order to accurately measure the focal length for ensuring the homogeneity of the refractive index, B.E.A. equally needs to perform more complete characterization of components during the R&D process. To meet their needs both in production and in the laboratory, B.E.A. chose a HASO3 128 wavefront sensor and its HASOv3 companion software.



Figure 1. Example of B.E.A.'s plastic lenses.

B.E.A.'s requirements...

B.E.A. provided detailed criteria for a metrology system to meet their needs. Precision and accuracy were, of course, the first priority. Immediately after the device's technical characteristics, B.E.A. wanted a reliable instrument that didn't require any particular environmental conditions, most notably an antivibration table.

Additionally, their specifications called for a device that required little space, rugged enough to withstand small shocks of everyday use, and easy to protect from dust and other contaminants. Finally, B.E.A. wanted a device that could be set up quickly and easily, without lengthy alignment procedures and that would measure components directly

without requiring additional optics to shape or collimate the source.



Figure 2. HASO3 128 GE is a new version of HASO3 128.

Why did B.E.A. chose HASO3 over other wavefront sensors or measurement systems?

B.E.A. chose a HASO3-128 Shack-Hartmann wavefront sensor and HASOv3 wavefront analysis software because they provided all technical characteristics needed for precision testing and, when compared to many interferometers and systems measuring by optical deflection, offered a far superior value thanks to their relatively low cost. What's more, HASO3-128 measures and displays high-resolution data in real-time, enabling the user to perform on-the-fly alignment procedures.

The reasons behind B.E.A.'s choice were the industry leading performances provided by HASO3 wavefront sensors, including:

- Ultra-precise, absolute measurement – HASO3-128 provides true absolute measurement of both phase and intensity with a remarkable accuracy of $\sim\lambda/100$ rms in absolute mode and $\sim\lambda/150$ rms in relative mode. In laboratory conditions where repeatability is essential, HASO3-128 offers unparalleled performance at $\sim\lambda/200$ rms.
- Wide dynamic range without compromising accuracy – The quality of HASO3's microlens

arrays, combined with their patented Dynamic Spot Tracking™ and Auto Spot Finder™, enables Imagine Optic's wavefront sensors to measure wide-ranging aberrations in even the most highly-convergent or divergent sources. With HASO, B.E.A. can choose the level of accuracy needed for each measurement, from several tens of lambdas up to $\lambda/100$ rms.

- High-resolution and a large, fully configurable, pupil size - HASO3-128 offers an exceptional spatial resolution of 16,384 measurement points on a 128x128 microlens array with a pupil diameter of 15x15 mm. This feature enables the sensor to measure optical components with wide diameters without the need for additional optical elements. Even more, HASOv3 enables users to custom configure the pupil aperture, whether it be inscribed or circumscribed, to match that of the component's specifications.
- Versatility - With the same device, B.E.A. can measure lenses, mirrors or any other optical component that generates a wavefront including those with a large numerical aperture (NA).
- Powerful, ergonomic and customizable software - HASO3-128 is delivered with HASOv3, considered by many to be the best wavefront analysis software available. Via one, fully customizable interface, B.E.A.'s engineers and quality control team can view both the phase and intensity profiles; visualize the wavefront's local slopes; perform both zonal and modal wavefront reconstruction; calculate Zernike coefficients; manage the pupil diameter; and access online help and tutorials.
- Guaranteed logistical and technical support - Imagine Optic is known worldwide for its outstanding technical support to ensure that every customer gets the most out of their products.

The proof is in the application - How B.E.A. uses HASO3 for precision quality control and advanced R&D

Measuring the quality of lenses

Since almost all the lenses used in B.E.A. products are designed to focus at infinity, or at extremely close distances, the reference point for measuring their optical quality is easy to determine. In one simple procedure that involves placing a collimated source (Imagine Optic's Laser Diode) between the lens to be characterized and the wavefront sensor, in such a way as to measure the wavefront parameters at infinite focus, accurate measurements are quickly achieved.

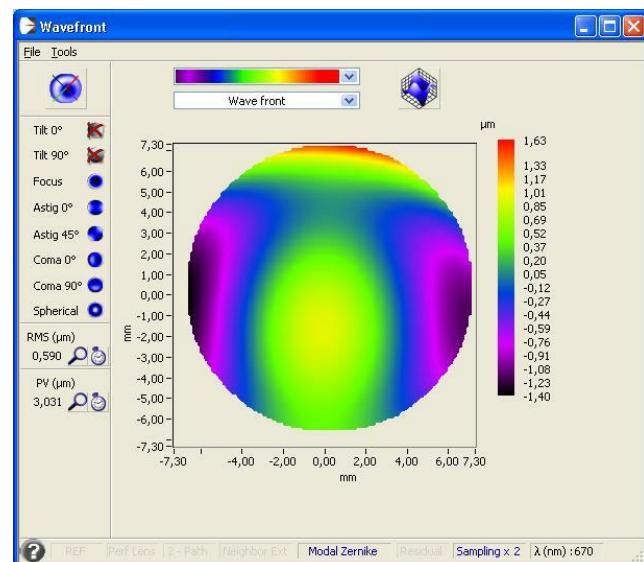


Figure 3. A wavefront profile as displayed in HASOv3 that was acquired using a HASO3-128 on one of B.E.A.'s plastic lenses.

Measuring the quality of mirrors (flatness)

Just as lenses are measured, B.E.A. uses HASO3-128 to characterize the flatness of plastic mirrors by analyzing the reflection of a collimated source. Moreover, this simple process enables their engineers to evaluate the mirror's mechanical and thermal behavior. As the figures below show, the

mirrors are rectangular and thereby create a highly-deformed far-field pattern, yet they are still easily measured by HASO3-128.

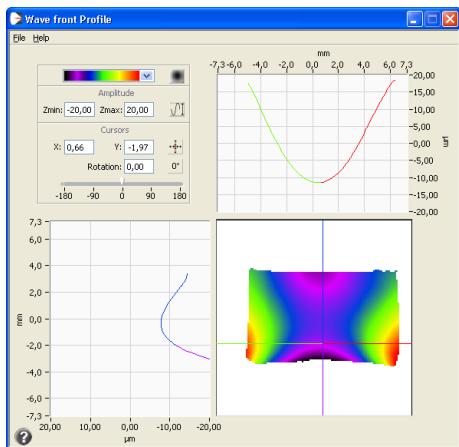


Figure 4. Measurements of a flat plastic mirror with mechanical and thermal constraints.

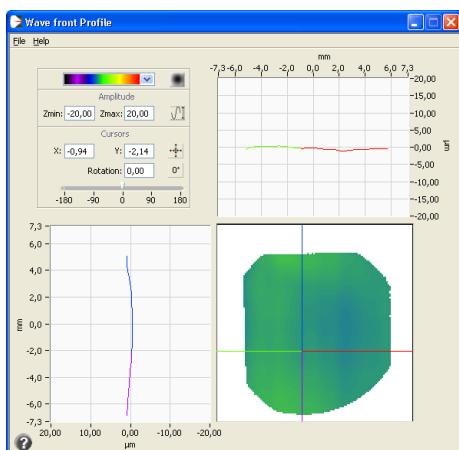


Figure 5. Measurements of a flat glass mirror.

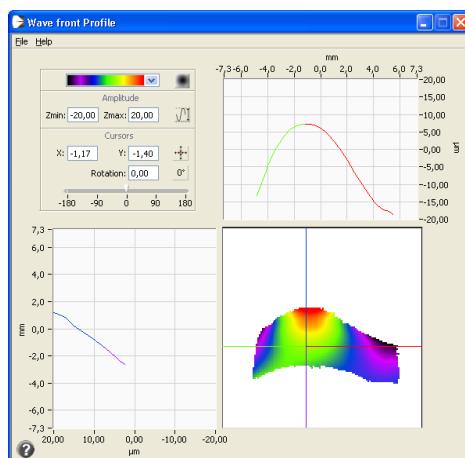


Figure 6. Measurements of a highly-deformed plastic mirror.

Characterizing the alignment & collimation of optical assemblies

B.E.A. uses the same HASO3-128 to verify the alignment and collimation of optical assemblies on R&D laboratory and on manufacturing test benches. In any optical system composed of multiple elements, the misalignment of one or more of the components introduces coma and astigmatism into the wavefront. These aberrations are easily measured by HASO3 and are displayed in a real-time, continuous histogram that is generated by HASOv3. To correct alignment errors, it suffices to adjust the position of the misaligned components as to reduce the values of the Zernike coefficients displayed in the histogram.

Measuring the focal length

Although B.E.A. uses their HASO3 128 in a variety of situations, its principal function is to measure and qualify the focal length of their lenses. This simple method requires placing the lens to be characterized between the wavefront sensor and a fibered diode laser mounted on a 3-axis translation stage equipped with a micrometric screw for displacement along the x-axis. The lenses themselves are mounted on a specially designed support structure enabling the engineers to easily position them with a high level of repeatability.

The illustration below in Figure 7 shows how, by using the formula $x = f \tan \alpha$ (where f is the focal length and x is the displacement along that axis), the angle α can be easily and precisely measured using the HASO3 128.

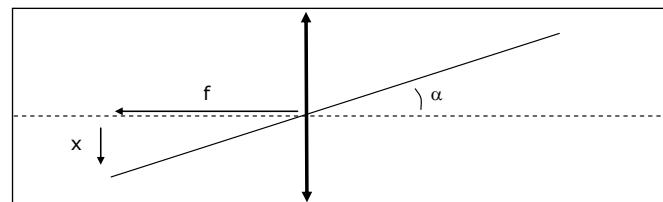


Figure 7. Illustration showing how the formula $x = \tan \alpha$ is used by B.E.A.

For each measured lens, the value of α is measured at 4 positions along the x-axis, and the data is fed through a system of overdetermined equations. The resulting f value is calculated using the ordinary least squares (OLS) method for statistical analysis. In order to limit the influence on measurements that off-axis aberrations can produce, x is maintained close to 0 (the optical axis). One potential drawback is that the lack of leverage in the micrometric translation along the x axis may result in a loss of accuracy.

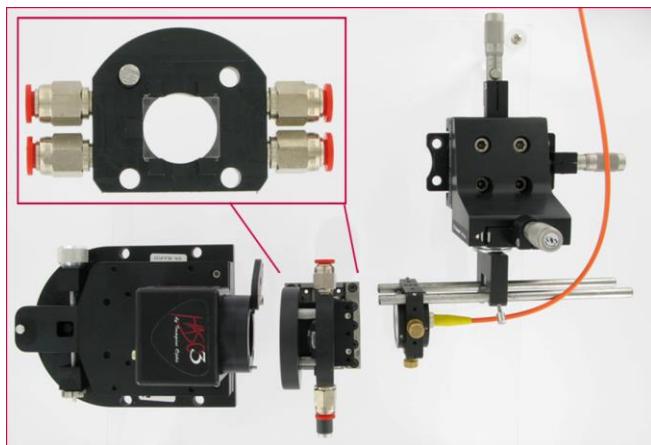


Figure 8. B.E.A.'s test bench setup. The assembly consists of a HASO3 128 wavefront sensor mounted on a $\Theta x\Theta y$ translation stage, the specially designed lens support structure (front view in upper left inset) and a fibered laser source mounted on a 3-axis micrometric translation stage. For some lenses, a vacuum system is added in order to ensure that the lens remains correctly positioned.

The photograph in Figure 8 displays the test bench setup and lens support structure in the inset.

For practical reasons, the x-axis displacement is set at 250 μm (one turn of the micrometric screw) and the HASO3 wavefront sensor's pupil is completely open to allow the beam to propagate freely. The first measurement is acquired with a negative shift and the last one with an equivalent positive shift. For each measured component, the alignment between the HASO3 wavefront sensor and the source is verified.

B.E.A.'s measurements show that the typical tolerance for their lenses is a focal distance of 24.5

$\text{mm} \pm 0.1\text{mm}$, in other words, a variation of only 0.4%. In order for the measurements to be useful for statistical analysis, the measurement precision that B.E.A. insisted on was 0.1%, which translates into an absolute precision within 25 μm of the focal distance. HASO3 - 128 provides B.E.A. with more than the necessary precision.

The table below illustrates a typical measurement result obtained by B.E.A.

dx, shift/mm	$\text{d}\Theta, \text{tilt}/\mu\text{rad}$	Lens Cav 1 2	
0	-16.75	0.0245	0.4111
0.25	-6.61	9.8237E-05	0.0011
0.5	3.54	0.9999678	0.0022
0.75	13.92		$f = 24.47$

Calculated EFL

Linearity

Conclusion

HASO3 has proven itself to be a polyvalent and invaluable tool for B.E.A. From the laboratory to the production floor, B.E.A.'s engineers use the unique functionalities provided by their HASO3 128 and its HASOv3 companion software to achieve results in optical alignment, quality control, thermal control and behavior under mechanical constraints. Although B.E.A. only uses a portion of HASO3's accuracy, the fact that their engineers can choose the level they want is a key value point.

For B.E.A., HASO has become an essential part of their quality efforts. In addition, for ensuring the quality of numerous components, HASO equally enables B.E.A. to maintain constructive dialogues with the manufacturers thanks to the details and accurate information on anomalies provided by HASO.

Thanks and credits

Imagine Optic would like to thank B.E.A. for the pictures and measurements provided for this application note.

About B.E.A.

B.E.A., headquartered in Liege, Belgium was founded in 1965 and has a worldwide presence with offices in Europe, United States, Asia, and Latin America. The company's expertise is in sensors for automatic doors and the cutting-edge technologies that go into making each sensor the most efficient and reliable in the industry. In addition, B.E.A. continuously develops new sensors aimed at other types of applications where the comfort and safety of the users is essential.

B.E.A.'s success has always been based on the vision and determination of its team around one common goal: "To Exceed Customer Expectations". This is done by providing excellent customer service, industry leading technical support and superior products.

Above all, B.E.A. is People...working for People.