Confirming optical system performance

High-accuracy lens measurement system holds the answer

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In today's global economy, optical components and systems are purchased from sources around the world, so the need for performing incoming inspection rapidly and efficiently has never been greater. Frequently, optical components that are sourced from domestic sales firms are actually manufactured elsewhere in overseas facilities with minimal quality control processes, metrology personnel and equipment.

A production facility or quality control lab requires inspection equipment with broad applicability and flexibility, typically operated by a technician. The LensCheck Bench from Optikos Corp. (Figure 1) is a step toward providing a cost-effective test platform for evaluating the performance of visible and near-IR optical systems over a broad range of test conditions. With space at a premium in most manufacturing and testing facilities, the compact device's tabletop footprint is less than 4 sq ft, allowing it to be located on a standard laboratory table; a floating table is not required. The system is portable and can be readily relocated and reconfigured within a few minutes for testing.

The LensCheck Bench allows an operator to easily confirm the basic performance of an optical component or system and to assess more complicated performance requirements. The light source and multiposition filter wheel enable lens and system testing using the spectral distribution encountered in actual use. It is not restricted to specific wavelengths and enables characterization of the various chromatic effects (such as longitudinal and lateral color or spherochromatism) that simply are not available with monochromatic testing techniques.

Figure 1. The LensCheck bench comprises a 58-mm clear-aperture collimator, a rotary stage and an image analyzer. Images courtesy of Optikos Corp.

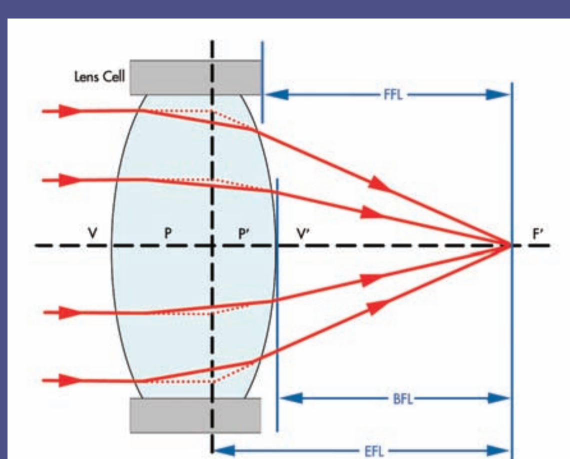

Figure 2. This diagram shows several first-order optical parameters.

Frequently, catalog optical components have tolerances in focal length and centration accuracy that require evaluation of first-order and imaging properties of the lens before it is installed in a system. For example, manufacturers of medical diagnostic equipment frequently incorporate off-the-shelf components including singlets, doublets and microscope objectives. Before mounting and aligning such components into a high-value assembly, it is prudent to confirm the performance of such components by measuring their first-order properties: effective focal length (EFL), back focal length (BFL), flange focal length (FFL) (Figure 2) and on-axis imaging performance (modular transfer function [MTF], resolution and/or spot size) under test conditions simulating their actual use.

To space components properly to achieve desired magnification and total track between object and image plane, it is essential to know the precise focal length and principal point locations in a lens relative to mounting surfaces. Thus, the ability to accurately measure parameters such as focal length, BFL and FFL greatly simplifies and accelerates the assembly of these systems, making the manufacturing process more predictable and deterministic.

This quick check assures that a compo-

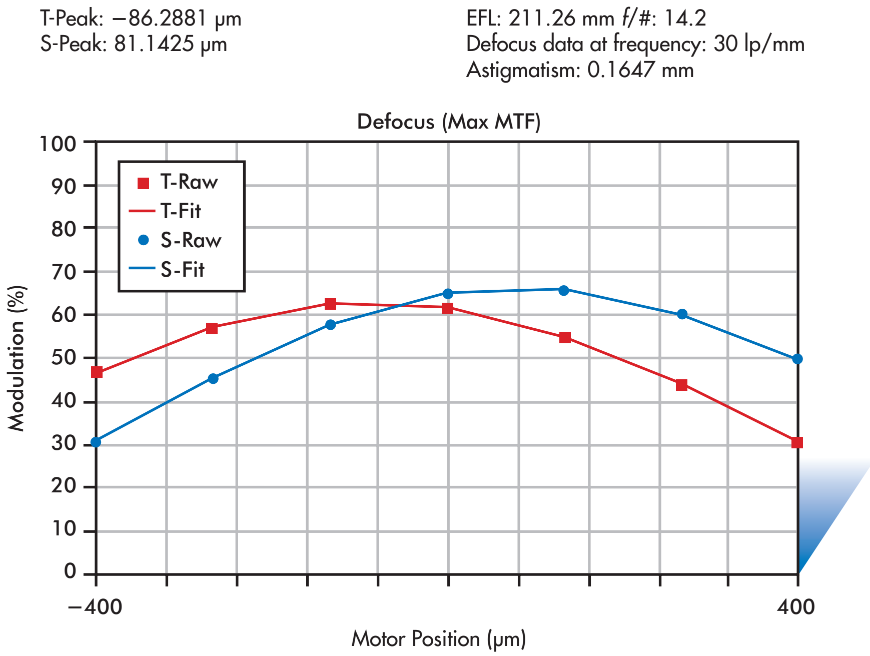

Figure 3. A typical mid-frequency MTF curve readily quantifies system astigmatism.

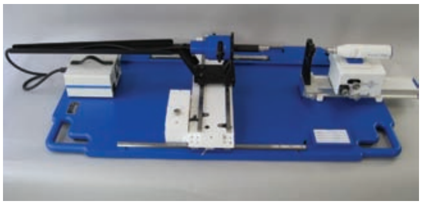

Figure 4. A tabletop bench allows for finite conjugate testing.

nent achieves its nominal performance and may safely be incorporated into a larger optical assembly.

Often, a quick inspection of the on-axis image blur determines that the blur shape is asymmetrical, meaning that the lens has a centration error and must be rejected. If a more quantitative metric is desired, the blur spot size (in X and Y) and the measured MTF can provide precise measurement of astigmatism – information that can be used to evaluate the impact on overall system performance.

How accurately can we measure these lens parameters? Consider a 50-mm-focal-length *f*/4 well-corrected, well-centered doublet in the visible spectrum (See Table 1).

Note that these capabilities scale with *f* number and focal length so that highly corrected faster systems can be measured to higher accuracy, and slower systems to lower accuracy. Typically, longitudinal aberrations in a highly corrected system may be measured to a fraction (<⅕) of the longitudinal diffraction depth of focus, allowing one to assemble a system with confidence that the predicted performance will be achieved. A typical through-focus MTF curve of a lens exhibiting moderate astigmatism (167 μm) is depicted in Figure 3. This lens, with an *f* number of 14.2, has a diffraction depth of focus (±2 λ $f/\#^2$) of approximately ±200 μm.

To obtain results to these accuracies, the lens under test must be properly fixtured and aligned relative to the optical bench axes. Also, all slides are instrumented with glass scale encoders so that derived calculations such as focal length (EFL = image shift/tan [θ]) can be performed to the requisite accuracy. Accurate measurement of MTF requires that stray light in the system be captured, and therefore use of a camera with an extended bit depth and dynamic range is essential. To achieve high throughput, patented use is made of VideoMTF software to measure blur spot size and MTF using real-time video capture.

We have seen a number of highly unusual systems requiring characterization over very wide fields (beyond ±90°) or very low *f* numbers. The Optikos LensCheck Bench allows a user to test lenses over fields of view extending to ±105°. The high-quality re-imaging objectives enable testing of lenses with numerical apertures as high as 0.8. In specialized cases using an immersion objective as part of the image analyzer relay, it has been possible to test optical systems that are part of fluorescence imaging systems with numerical apertures approaching 1.5.

While in many cases an optical system is used at infinite conjugates, numerous optical systems are intended to relay images and must be tested at their designed finite conjugates. For example, a short 4:1 finite conjugate relay system should be tested at the actual finite conjugates of use. In most cases, the design performance at infinite conjugate would be substantially degraded. Optikos has developed the ability to perform these tests and to characterize distortion and other field aberrations to extreme precision by incorporat-

50-mm EFL *f*/4 Visible Doublet – Typical Measurement Capabilities	
Paraxial focal length	EFL ±<0.1%
Diffraction cutoff frequency (wavelength = 0.5 μm)	500 lp/mm
MTF accuracy	<2%
Field curvature	<5 μm
Longitudinal astigmatism	<5 μm
Flange focal length	±<10 μm
For a highly corrected wide-field (±30°) *f*/4 objective with a 50-mm effective focal length	
Distortion	<0.1%
Field plane tilt	<1 arcmin
Illumination uniformity and drop-off	<1%

Table 1.

ing high-accuracy encoders into the image analyzer stages. Distortion accuracy of less than 0.1 percent can be obtained over a 100-mm field, though it is usually limited by the distorted blur shape formed by the lens.

All of this is accomplished through the use of a USB-based motion-control system working closed loop with encoders on multiple axes. The VideoMTF software assures a level of metrology accuracy and precision not previously available at this price point and unit size.

Collectively, the Optikos LensCheck Bench brings a new level of capability to production facilities and allows technicians to make measurements that otherwise would have to be made by development engineers. This enables manufacturers to qualify every incoming product quickly and reliably, while greatly minimizing the costs and risks of substandard complete assemblies.

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