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A new technique simplifies measurement of homogeneity to decrease measurement time and improve repeatability.

Measuring Homogeneity with the FizCam 2000

Introduction

Laser interferometry is a long-standing method for measuring the homogeneity of optical materials. 4D Technology's FizCam 2000 laser interferometer, which employs Dynamic Interferometry® and a short coherence laser source, provides a much simpler and repeatable method for measuring the homogeneity of both bulk material samples and finished optics. The procedure is made possible by two significant advances: the ability to measure solid cavities, and the ability to isolate reflections from parallel planar surfaces.

Solid Cavity Measurements

In most laser interferometers the test or reference surface must be translated to acquire phase data in sequential camera frames. The FizCam 2000, however, uses patented, polarization-based Dynamic Interferometry to acquire all phase data simultaneously. The result is extremely short integration times that make the system highly insensitive to vibration, air turbulence and other noise.

The FizCam 2000 also eliminates the need for translating the reference surface relative to the test surface to acquire phase data. This feature makes it possible to measure the "solid cavity" of an optic, using the front and back surfaces as the test and reference. The ability to measure solid cavities enables the simplified homogeneity measurement procedure described below.

Isolating Reflections

Virtually all Fizeau interferometers utilize long coherence laser sources. With these systems interference occurs between reflections from all pairs of surfaces in the beam path. When more than two reflective surfaces are in the beam path, interference occurs between all pairs of reflections resulting in a complex interferogram from which it is difficult or impossible to separate the fringes to measure any particular surface.

To overcome this difficulty, the FizCam 2000 uses a short coherence (~300 µm) laser source that isolates the interference from any particular pair of reflections in the beam path. An internal "Path Matching" mechanism lets you equate the reference arm of the interferometer to the optical path difference (OPD) of any particular pair of surfaces. Once the path is matched all other cavities fall outside of the 300 µm coherence length and do not contribute fringes to the interferogram.

Note: More information is available in the 4D Application Note, "Path Matching with the FizCam 2000."

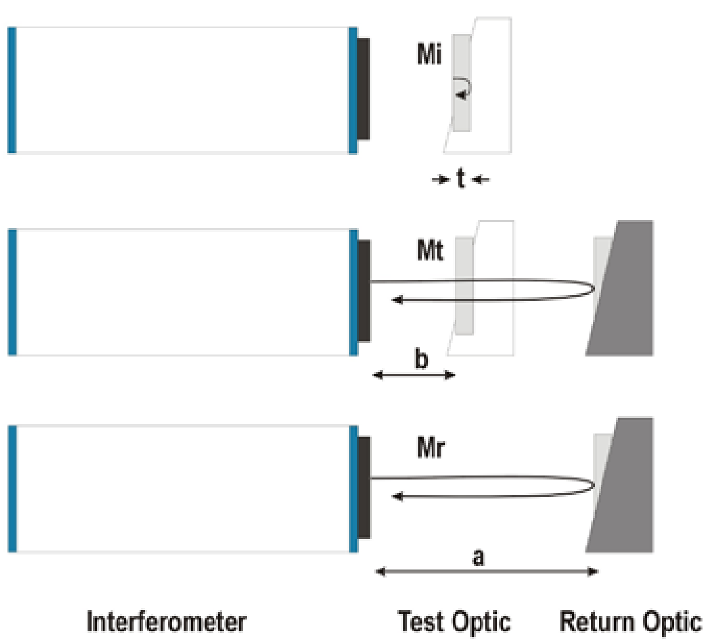

Figure 1. An improved homogeneity procedure requires only three measurements and only one setup.

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Conventional Homogeneity Measurement

Spatial inhomogeneity of an optic's refractive index can be caused by the melting process, by variations in density or by permanent stresses due to temperature gradients during cooling. Homogeneity is obtained by measuring the transmitted wavefront error (the deviation of a test beam as it passes through the optic), then isolating and removing the contributions of the surfaces.

One method for removing the surface contributions is by immersing the optic in an index-matching liquid, with high-quality windows on either side. This setup, however, requires special fluids which are difficult to clean and are potentially hazardous. It also introduces more components and thus more error sources.

A second method, often used to characterize raw material, requires a sample that has been polished to reasonable optical quality. The sample must be polished with sufficient wedge to remove the reflection of the rear surface such that fringes only develop between the front surface and transmission flat. Four measurements are required using a standard, temporal Fizeau interferometer:

- the empty cavity
- the sample in transmission
- the front face in reflection
- the back face in reflection, either measured through the sample (if it is sufficiently wedged) or measured after the sample is flipped to face the interferometer.

This procedure requires a great deal of care and time to produce accurate results. For samples with little wedge the procedure requires both sides of the optic to be temporarily coated with anti-reflective material and subsequently stripped, a process that is time-consuming, messy and potentially damaging to the optic. The optic must also be flipped about its X axis, which requires precision mounts and very accurate alignment. Finally, since the procedure is performed on a traditional, temporal phase-shifting interferometer, vibration and air turbulence must be tightly controlled.

Improved Method for Measuring Homogeneity

With a new procedure using the FizCam 2000 the homogeneity of samples with nominally parallel faces can be obtained from only three measurements, with a single test setup:

Mi = solid cavity measurement

Mr = empty cavity measurement

Mt = the sample in transmission.

Figure 1 shows these three measurements.

With n as the nominal index of refraction, the derivation for homogeneity is given as:

[n*(Mt-Mr)-(n-1)*(Mi)]/2.

The procedure for measuring homogeneity with the FizCam 2000 is as follows:

1. Mount and position the transmission flat (t-flat). A spot should appear on the FizCam's Alignment Monitor. Adjust its tip and tilt such that the beam passes through the center of the crosshairs on the Monitor.

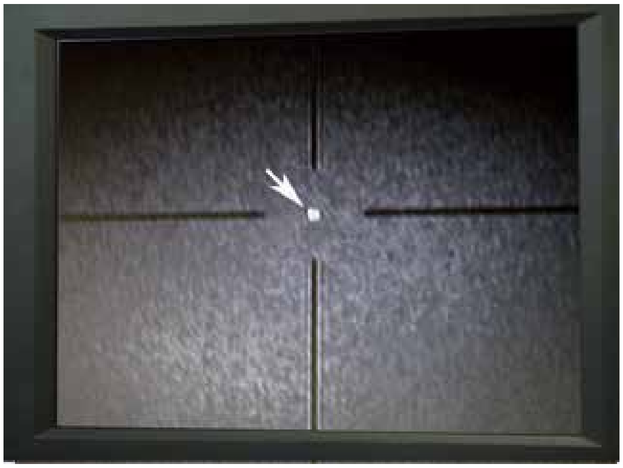

Figure 2. Both the test and reference beams should pass through the crosshairs on the Alignment Monitor.

2. Position the test sample as close to the t-flat as practical. You should now see two additional spots on the Alignment Monitor reflected from the front and back surfaces. Adjust the sample's tip and tilt such that the beam from its front face (the face closest to the interferometer) passes through the crosshairs on the Alignment Monitor.
3. Position the return flat as close to the test optic as practical. Adjust its tip and tilt such that its spot passes through the crosshairs on the Alignment Monitor.
4. Adjust the **Zoom** using the switch on the FizCam's hand controller until the test sample is entirely within the aperture (as shown on the 4Sight **Live Video** screen).
5. Place a card against the return flat, then use the **Focus** switch on the hand controller to bring the card's edge into sharp focus.

Note: Once Focus and Zoom are set they should not be adjusted for the remainder of this procedure.

6. Block the return flat. This will improve contrast for the solid cavity measurement.
7. Set the **Path Match** distance for the solid cavity measurement:
   a. Choose **Tools > Pathmatch Controller** to open the Path Match dialog box.
   b. Click and drag the red box in the plot to a representative location on the test sample.
   c. Enter a scan range centered about the OPD. For the solid cavity measurement the OPD is the thickness of the optic multiplied by its index of refraction. For example, if the sample is roughly 5 mm thick with an index of 1.5, you might enter a **Center** value of 7.5 mm and a **Range** of ±1 mm. The more precisely you know the OPD the shorter the range can be, and thus the faster the scan.
   d. Click **Auto Pathmatch**. The system will scan through the range and will plot the average fringe modulation of the pixels in the red box. A modulation peak will occur at t*n (the thickness times the index), and the system will automatically move the path match mechanism to that distance. If the **Automatic Fine Tune** option is selected then the system will perform a second, high-resolution scan before moving the mechanism.

In the 4Sight Live Video screen you should now see a single set of fringes generated by reflections from the front and back of the sample.

Note: More information is available in the 4D Technology application note, "Path Matching with the FizCam 2000."

8. Click the **Camera Settings** button, then adjust the **Gain** and **Exposure** values to just below saturation.
9. Choose **Edit > Optical Parameters** and set the **Wedge Factor** to 0.5.
10. Make the Mi (solid cavity) measurement. You can take a **Single** measurement, but an **Average** of 16 or more measurements is suggested for improved accuracy.
11. Make the Mt (transmitted wavefront) measurement:
    a. Unblock the return flat.
    b. Set the Path Match to the entire cavity length. Per Figure 1 this equals a+ (n-1)t. In the Live Video screen you should now see fringes between the t-flat and return flat.
    c. Adjust the tip and tilt of the return flat to minimize the number of fringes.
    d. If necessary adjust the **Gain** and **Exposure** values to just below saturation.
    e. Measure Mt (again, an Average measurement is suggested).
12. Make the Mr (empty cavity) measurement:
    a. Remove the sample from the test beam.
    b. Set the **Path Match** distance to the empty cavity length.
    c. Adjust the tip and tilt of the return flat to minimize the number of fringes.
    d. If necessary adjust the **Gain** and **Exposure** values to just below saturation.
    e. Measure Mr (Average measurement is suggested).
13. Save the three measurements to disk with names that will make them easy to distinguish later.

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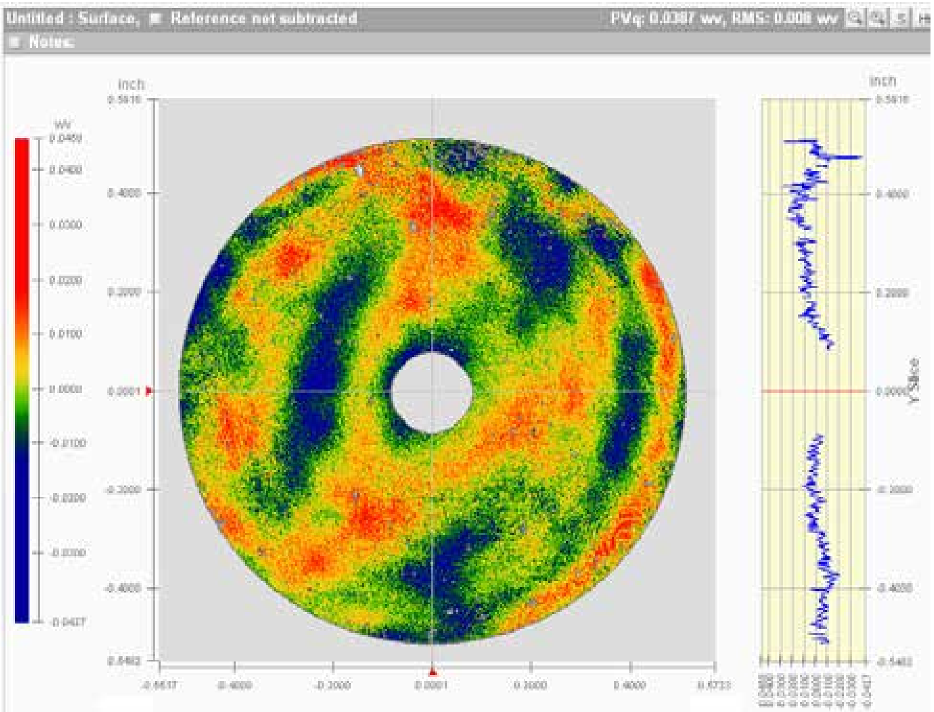

Figure 3. Homogeneity of a glass disk measured using the FizCam 2000.

The 4Sight transformation functions make it easy to calculate homogeneity from the three measurements. A script is also available to automatically calculate homogeneity.

Figure 3 shows a completed homogeneity measurement for a 2.8 mm thick transparent glass disk.

Tip: Keep the cavity length as short as possible. It can also be helpful to stir the air in the cavity with a fan—with the FizCam 2000 fast-moving turbulence is easier to average out of a measurement than slow-moving air.

Note: More highly wedged samples can be measured with the FizCam 2000 using the 4-measurement, non-flipping method.

Complete Characterization of Planar Optics

The FizCam 2000 makes it possible to measure planar optics more thoroughly than previously possible, all with a single test setup. From the three measurements described above, and one more in which the back surface is measured through the optic, you can obtain:

- transmitted wavefront error
- the shape of both surfaces
- homogeneity
- wedge
- point-by-point optical thickness.

Application notes are available from 4D describing all of these measurements.

The FizCam 2000 is a unique instrument that enables novel measurements that simplify the characterization of flats. No other system makes it possible to characterize flat optics as completely, with a single test setup.

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