A new technique for vibration-insensitive measurement of TWE improves repeatability by more than 7X.

Measuring Transmitted Wavefront Error with the FizCam 2000

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Introduction

Laser interferometry is a long-standing method for measuring transmitted wavefront error (TWE), the deviation of a beam due to its passage through an optic. 4D Technology's FizCam 2000 provides a greatly improved, more repeatable process for measuring TWE that takes advantage of two advances: the ability to measure a "solid cavity" and the ability to isolate reflections from parallel planar surfaces. The new procedure eliminates errors due to the cavity, requires only a single measurement, and needs no optics other than the test piece itself, for accurate, vibration-insensitive measurements.

Solid Cavity Measurement

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. Figure 1 shows the setup for a solid cavity measurement (Mi). The ability to measure solid cavities enables the TWE measurement procedure described below.

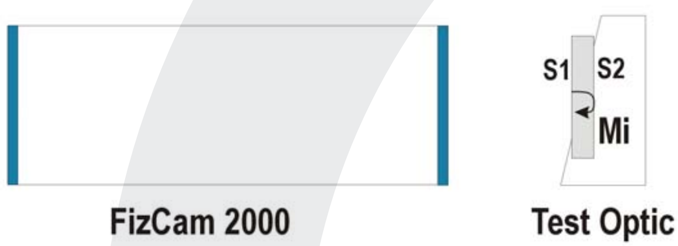

FIGURE 1. Solid Cavity TWE measurement setup

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.

Improved Method for Measuring TWE

Transmitted Wavefront Error (TWE) is a combination of the front and back surface shape, inhomogeneity of the optical material and deviation in parallelism between the two faces. Traditionally, TWE has been measured using the setup shown in Figure 2. First, the empty cavity is measured (Mr), then the test optic is inserted into the cavity and a second measurement is taken (Mt). TWE is given as Mt - Mr.

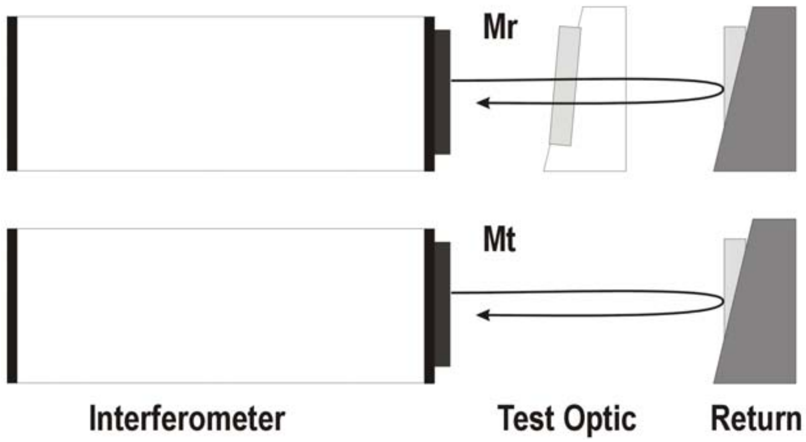

FIGURE 4. Traditional Transmitted Wavefront Error measurement setups

The method presents several important shortcomings. First, the additional reference and return optics create an air cavity in which turbulence and vibration will degrade the measurement. Second, the reference optics and mounts can represent a significant expense as well as introducing additional error sources. And third, the method requires two measurements which must be calibrated and controlled.

With the FizCam 2000, TWE can be calculated directly from a single, solid cavity measurement with no additional optics (Figure 1). Since acquisition is nearly instantaneous the measurement is virtually insensitive to turbulence and air movement, even if the optic must be placed a long distance from the interferometer. 4Sight data analysis software, included with the FizCam 2000, makes it simple to acquire the solid cavity measurement and to compute TWE.

Note: A transmission flat can be in place but is not required and will reduce fringe contrast.

The derivation for determining TWE is as follows:

TWE = S1-S2 + n(S2-S1)

Mi = n(S2-S1)

S1-S2 = -(Mi/n)

TWE = Mi - Mi/n

TWE = (1-1/n)*Mi.

The solid cavity method works best for measuring the TWE of optics with $< 20 - 30$ fringes of wedge.

The procedure for the solid cavity TWE measurement is as follows:

1. Place the test optic in a mount with tip, tilt, X and Y adjustment, and position it as close to the FizCam 2000 aperture as is practical.
2. While viewing 4Sight's **Live Video** screen, use the X and Y controls to center the optic.
3. Viewing the FizCam's Alignment Monitor, adjust the tip and tilt of the test optic such that its return beam falls directly on the center of the alignment crosshairs. When the beam is in the exact center it will dim.

Note: If the test optic has significant wedge, two return spots will appear on the monitor. Adjust the tip and tilt so that the two returns are equally far from the center of the crosshairs.

4. Viewing the **Live Video** screen, adjust the **Zoom** using the switch on the hand held controller until the optic is entirely within the field of view.
5. Adjust the **Focus** switch on the hand held controller to minimize diffraction rings near the edge of the optic.
6. Adjust the **Path Match** distance:
   a. Within 4Sight open the **Pathmatch Controller** dialog box (Figure 3).

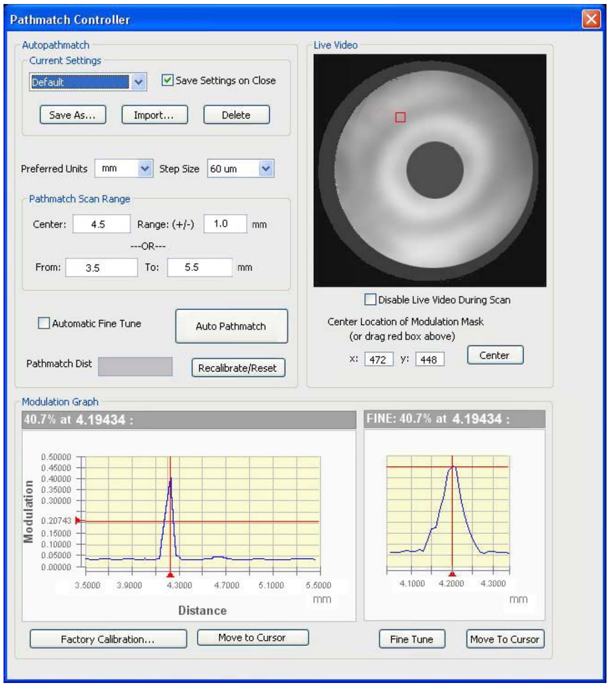

FIGURE 3. Pathmatch Controller dialog box.

b. Click and drag the red box in the live video area to a location on the test optic.

c. Enter a scan range centered around the estimated optical path difference (OPD). For a solid cavity measurement the OPD is t*n, the thickness of the optic multiplied by its index of refraction. For example, if the optics is approx. 3 mm thick with an index of 1.5, you could enter a **Center** value of 4.5 mm and a **Range** of ±1mm. The more precisely you know the OPD the shorter the range can be, and thus the faster the scan can be.

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.

You should now see a single set of high quality interference fringes in 4Sight's Live Video screen.

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

7. Click the **Camera Settings** button, then adjust the **Gain** and **Exposure** values to just below saturation.
8. Choose **Edit** > **Optical Parameters** and set the **Wedge Factor** to 0.5.
9. Make the solid cavity measurement. You can take a **Single** measurement, but an **Average** of 16 or more measurements is suggested for improved accuracy.
10. To calculate the transmitted wavefront error choose **Modify** > **Arithmetic** > **Z-Scale**. Scale the measured dataset by (1-1/n). The resulting dataset is the transmitted wavefront error.

Comparing Traditional and Solid Cavity TWE Measurements

Figure 4 shows the transmitted wavefront measurement for a 12.9 mm thick shear plate, using both the traditional method (top) and the solid cavity method (bottom). Both methods report approximately λ/100 peak-to-valley error; however, the solid cavity measurement provides a much clearer image of the error induced by mounting stress from the 3-jaw chuck.

Optical Metrology for a Dynamic World

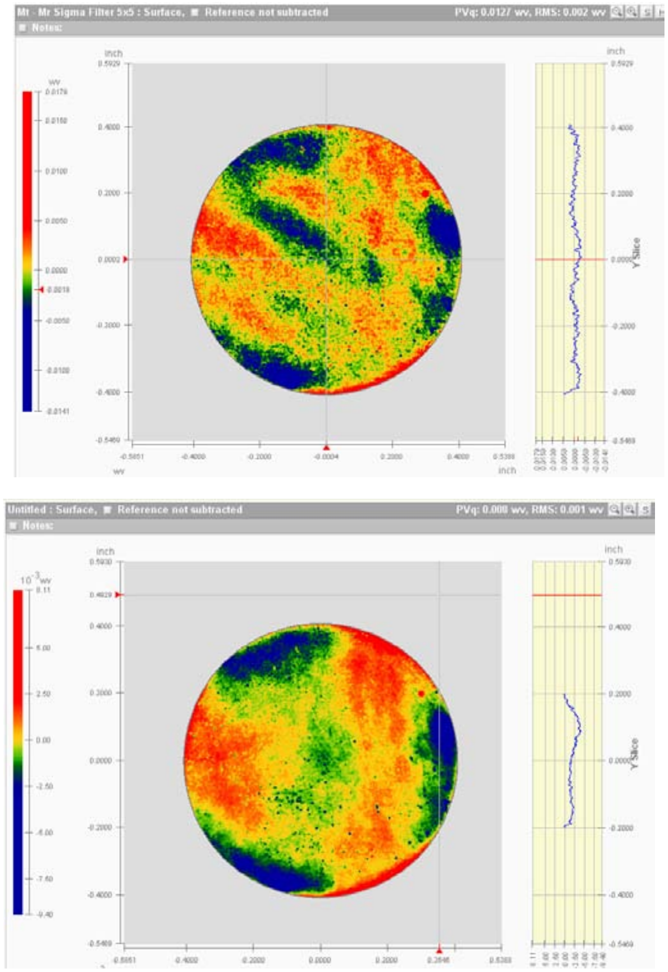

FIGURE 4. Transmitted wavefront error measured with traditional (top) and solid cavity (bottom) methods. A sigma filter is applied to both datasets to deemphasize high frequency spikes.

Improved Repeatability

The solid cavity measurement technique is more repeatable because of the elimination of the air cavity and because only one measurement is required versus two in the traditional method.

As an example, a 70 mm square window approx. 2 mm thick was measured. 160 measurements were taken of the empty cavity, the transmitted wavefront measurement and the direct cavity. The RMS repeatability of the traditional method (taking into account the repeatability of both the empty cavity and TWE measurements) was found to be 0.003 waves. The repeatability of the solid cavity measurement was found to be 0.0004 waves, a 7.5X improvement over the traditional method.

Complete Characterization of Flats

The FizCam 2000 makes it possible to measure a planar optic more thoroughly than previously possible, all with a single test setup. Using a combination of solid cavity and other measurements 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.