Tips to ensure accurate, vibration-insensitive, long-standoff measurements.

Best Practices for Long Path Measurements

Mike Zecchino, Michael North-Morris

Introduction

Dynamic Interferometry is a near-instantaneous method for measuring surface shape and wavefront quality, even in the presence of vibration and air turbulence. This innovative technology is incorporated into 4D Technology's PhaseCam® Twyman-Green configuration interferometers, which enable measurement of large optics, in difficult environments and over long test paths. Wavelengths ranging from 632.8 nm through 1.55 µm, as well as high power and multi-wavelength versions, enables PhaseCams to measure a wide range of large diameter and long radius of curvature optics.

The following tips for each step of a measurement will help guarantee excellent measurement results with PhaseCam systems, particularly for long path measurement of large optics.

Setup

As a dynamic measurement system, the PhaseCam does not require an air isolation table or air flow controls to perform well. Its ability to measure despite vibration and turbulence gives users the freedom to optimize the test setup for the best measurement accuracy, not to accommodate the interferometer.

The PhaseCam can be mounted with its optical axis in the vertical or horizontal plane. The instrument's swivel feet and kinematic mounts are designed to accommodate some curvature in the table or mount, ensuring accurate system alignment. The feet and clamps should always be used to prevent the interferometer from deforming to the shape of the table, which could lead to misalignment of the internal optics.

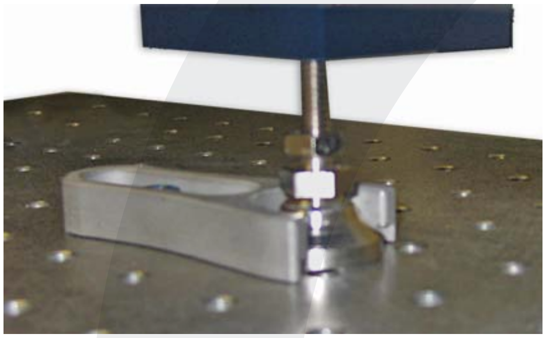

Figure 1. Always mount system using swivel feet and kinematic clamps.

Test Path

PhaseCams can be employed in most traditional interferometer test setups. As a polarization-based system, however, care should be taken to avoid folding the test beam where it is converging or diverging, which can induce polarization changes across the beam that will alter the OPD data. The beam should always be folded where it is collimated to avoid inducing polarization errors or requiring specially designed coatings.

Alignment

When measuring a spherical element it is sometimes difficult to rough align the beam, particularly at non-visible wavelengths. A simple alignment procedure is as follows:

1. Remove the diverger optic. The output beam will be collimated.
2. Align and center the collimated beam on the test optic.
3. Adjust the tip and tilt of the test optic such that the beam returns into the interferometer aperture. Circular fringes may now appear on the alignment screen, depending on the optic.
4. Install the diverger lens, being careful not to bump the system and alter the alignment. The system should now be roughly aligned.
5. Place an iris or card at the focal point and fine-adjust the alignment, tip/tilt and focus.

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Diverger Lens and Zoom

Optical zoom provides a range of F-numbers for a particular diverger, allowing you to view and measure a range of diameters at full aperture, for highest lateral resolution. Excessive zoom, however, can cause a significant proportion of the light to be lost and not reflected back to the interferometer. Therefore, use a diverger lens that is slightly faster than the test optic and apply a small amount of zoom to fill the aperture. This will ensure the highest lateral resolution with the shortest integration time and best vibration isolation.

When measuring small optics you can insert a spacer ring between the lens and instrument to pull in the focus range for “macro” imaging. Spacers are available from 4D for this purpose.

Focus

The focal range for PhaseCams is specified at ± ½ inch. This is the range for planar optics only, which are typically not measured with the small-aperture PhaseCam. PhaseCams are primarily used with a diverger lens to measure optics with curvature. The diverger lens magnifies the focal range to many hundreds of meters, making it easy to focus in most test setups.

When focusing on featureless optics you can either add fiducial marks to the surface or hold a card up to the surface of the optic to enable focusing. The degree to which you need to focus depends on the lateral resolution requirement of the particular measurement.

Beam Ratio

Balancing the intensity of the test and reference beams maximizes the contrast of the interference fringes, resulting in the best measurement quality. With many interferometers a pellicle is required to balance the beams when measuring highly reflective samples. PhaseCams, however, provide an integral Beam Ratio adjustment to let you adjust contrast on the fly. Some PhaseCams include motorized beam ratio adjustment on the Electronics Box for remote operation. To maximize fringe contrast:

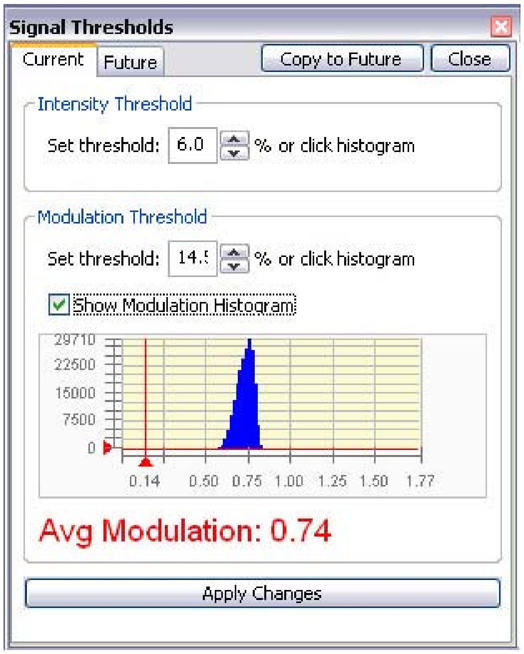

Figure 2. Modulation Threshold is shown in the Signal Thresholds dialog box.

1. In 4Sight, open the Measurement Console and choose Live Video.
2. Choose **Measure > Modulation Threshold** to open the Signal Thresholds window.
3. Check the Show Modulation Histogram to display a histogram of the modulation.
4. Adjust the Beam Ratio to maximize the Average Modulation
5. After adjustment you may need to adjust your camera settings to account for lower light levels.

Camera Settings

In conventional interferometers the amount of light reaching the camera is often controlled by a neutral density filter wheel which optimizes camera exposure by rejecting a portion of the incoming light. But throwing away light is rarely beneficial for measurement quality. A better option is to optimize the camera gain and integration time to provide the best exposure. It is best to keep the integration time as short as possible to exclude the effects of vibration, and to keep the gain as low as possible to minimize camera noise. Typically the gain is adjusted first and then integration is optimized from there. Several fringes should be present across the pupil, and the average intensity should be 125-250.

Averaging multiple measurements will also help decrease the impact of camera noise.

Masking

Masks are used to select areas of the data for inclusion in the measurement results. 4Sight offers four types of masks, each for specific purposes: measurement data set.

- The Detector mask eliminates pixels from the data prior to phase unwrapping. It is akin to physically blocking a portion of the pupil. Use the detector mask to exclude areas of no signal to avoid errors during phase unwrapping (Modulation and Intensity thresholds can also be used for this purpose).
- The Analysis mask is applied after phase unwrapping and can be altered at any time. It is used to isolate portions of existing data for further analysis or comparison.
- The Terms mask determines the set of pixels to be used for terms removal. For example, in data with multiple islands or steps, one island of data can be isolated; tilt will be removed to flatten this region, and these settings will them be applied to the entire data set as well. Regular terms removal should not be used while a terms mask is in use to avoid unexpected results.
- The Pupil mask is automatically set to encompass circular data sets. It can also be set manually to establish a circular region with a normalized coordinate system from which Zernike terms will be calculated.

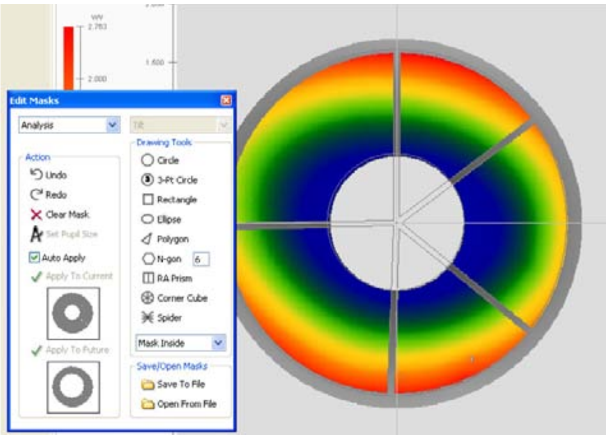

Figure 3. Masks can be used to select which data are included in a measurement. This Analysis Mask excludes the support structure for a secondary mirror in a telescope system.

Modulation and Intensity Thresholds

These settings in 4Sight help you identify and isolate reliable pixels (those exhibiting sufficient modulation and contrast) and exclude areas of data dropout and noise. Like masks, the thresholds let you select data to be included in the measurement. The thresholds, however, let you quickly select complex, irregular areas of data that may differ from measurement to measurement. Histograms in the Signal Thresholds dialog box make it easier to optimize the thresholds.

Averaging

Averaging in a dynamic interferometer removes random and quasi-random effects from data, including turbulence, thermal gradients over long measurement paths and camera noise. Averaging 16 or more measurements typically improves results. A greater number of measurements in the average may further improve results but will also increase measurement time.

Tip: If air movement is slow or stagnant, a longer series of measurements, or longer delay between measurements, may be required to average out the effects. Counter to what you may expect using a temporal phase-shifting interferometer, stirring the air to increase movement can reduce the measurement time and improve results with a dynamic system.

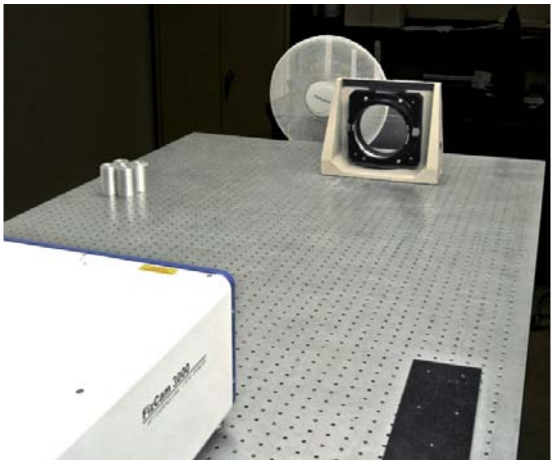

Figure 4. Averaging data removes the effect of air turbulence from measurements. Stirring the air with a fan can improve results when the air flow is slow—counter to what you might expect with a standard interferometer.

Filtering

4Sight includes a number of filtering options to help tame noisy data. Use the Fourier, Smoothing, Median and Sigma filters to remove noise spikes and other irregularities.

Display

4Sight includes dozens of display options to enhance the most important aspects of measurement data. In addition to using various analyses, you can also view each of the data sets included within a measurement. For example, you may view the raw interferograms to aid in placing fiducials, or you may look at the modulation data to determine whether good data is dropping out. The Measurement Flow lets you see how each step of processing has affected the data. Cross-sections, palette options, data transformations, etc., may also highlight particular aspects of the data.

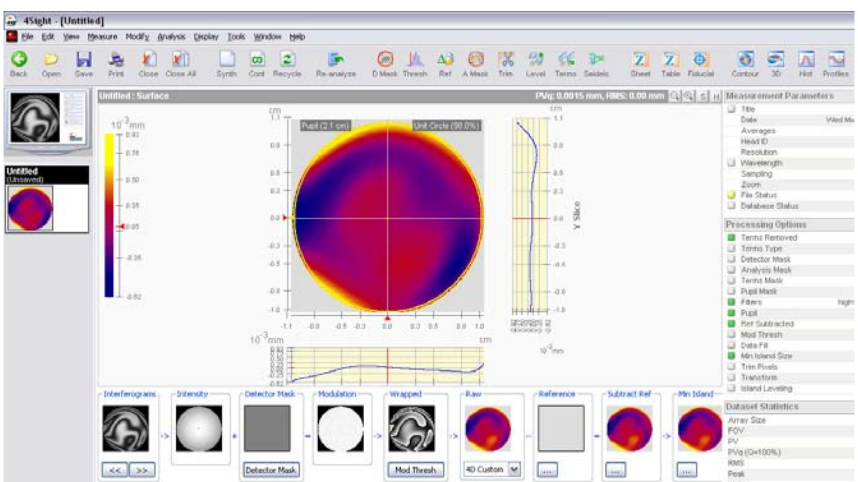

Figure 5. Measurement Flow

Conclusion

4D Technology's PhaseCam dynamic interferometers make it easy to complete complex, critical measurements in difficult environments. Measurements that once required long sessions in the middle of the night to obtain usable data can now be completed in a few minutes, with minimal accommodations for the measurement system.