ZYGO CORPORATION'S

FlashPhase™ Data Acquisition System

interferometry in unstable environments

Unstable Environments

Standard phase shifting interferometry provides the highest precision and lowest mainframe uncertainity available. However, vibration and turbulence severely affect interferometric measurements, especially for applications with large air volumes such as long cavities or large test parts.

Typical solutions have included moving the test to the stable environment of R&D or QC, waiting until the lab is quiet on weekends or at night, or rigging elaborate test set ups to minimize environmentally-induced measurement noise.

Frame Rate Solutions

A better solution uses short bursts of phase data collection followed by frame averaging. This approach freezes the effects of the unstable environment. Technically this can be accomplished in several ways. Most of the solutions are hardware based to reduce the computational load on the PC. These systems use multiple cameras or optical paths to segment the interferogram into three or more phase-shifted images. As a result, they are optically complex and very expensive.

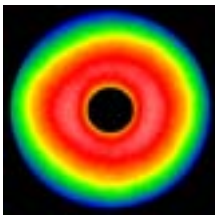
Enter FlashPhase™

FlashPhase™ is a revolutionary computer-based solution that adds high-speed data acquisition to ZYGO's standard MetroPro™ software. By coupling simple Fizeau geometry with an easy-to-use software enhancement, it achieves the same performance as the expensive, complicated hardware approaches, at a fraction of the cost. Since FlashPhase™ does not modify the interferometer, it does not affect the standard high performance of conventional PMI data acquisition. Application by application and test by test: FlashPhase™ speed or PMI precision. You choose.

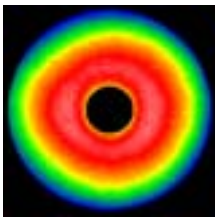
Compare for Yourself

PSI is the standard of performance. But when vibration and turbulence limit your ability to measure, FlashPhase™ gets you the data.

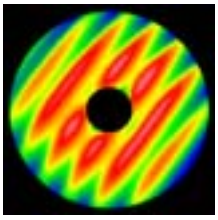
All frame rate systems trade speed for uncertainty, but a quick comparison of the plots below show the high correlation between FlashPhase™ and standard PMI data. FlashPhase™ data is highly repeatable.



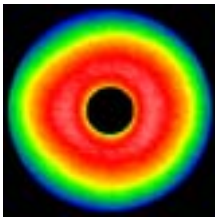
Phase – Stable



FlashPhase™ – Stable



Phase w/Vibration



FlashPhase™ w/Vibration

Frame Averaging Minimizes Noise

Noise tends to be random. When N number of sequentially acquired frames are averaged, the amplitude of random noise

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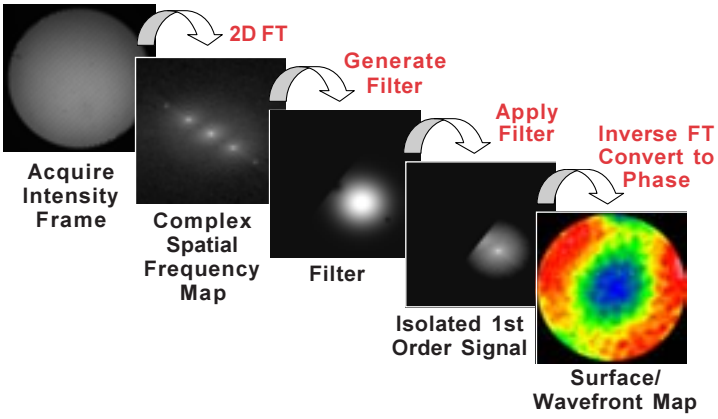
decreases by 1/(sqrt (N)). To cut the noise by half, four data sets are averaged. In MetroPro™, you select the number of averages to optimize your measurement. The system then takes over, acquiring all the data sets and averaging the data, giving you the results you need.

How it Works

Traditional PMI methods determine phase by modulating the cavity and capturing multiple intensity frames. Unfortunately, this method takes too long to make measurements in an unstable environment. FlashPhase™ solves this problem by capturing data at high speed, then averaging the phase information extracted from each individual intensity frame.

Acquire a single frame of intensity.
Apply a 2D Fourier Transform.
Isolate the 1st order signal
Perform an inverse 2D Fourier Transform
Convert to phase heights



Easy to Set Up

ZYGO interferometer's set up and measurement are easy.

Focus on the surface of the sample
Null the interferometer using the alignment stage
Set the cavity tilt with the aid of a software generated alignment target (Nominally, 30 fringes)
Measure
Analyze using the power of MetroPro™

Easy to Calibrate

As noted above, FlashPhase™ requires the interferometer wavefront to be tilted. Calibration easily removes any resulting wavefront errors. In many instances no calibration is required. For example, tilt-induced wavefront error for large aperture systems (>300 mm) are negligible (<λ/20).

Other surfaces, such as fast transmission spheres, (< f/1) can have errors larger than this value. To remove these errors, calibration is simple:

Insert a reference surface and align to the same tilt as the test part set up.
Measure the part,
Save the wavefront in the SysErr.dat file,
Click on "system error subtract".

Your system is now calibrated.

Shuttering – the Next Level

In extreme environments FlashPhase™ gives GPI HS™ and VeriFire™AT a real boost. Camera shuttering, available in these systems, is software-controlled and user-selectable. Shuttering down to 30 microseconds freezes even the most severe environments. Once the fringes are frozen, FlashPhase™ measurement proceeds as normal.

Why FlashPhase™?

FlashPhase™ is the right solution. No other option gives you the flexibility of FlashPhase™ speed and PSI precision, the best of both worlds.

FlashPhase™ is easy to use, easy to calibrate, easy to upgrade, and backed by Zygo Corporation's worldwide sales and service.

To schedule a demo, visit www.zygo.com or call 1-800-ZYGO NOW.

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SB-0332 5/04

Measurements in a Flash!

Interferometric measurements in a poor environment are challenging to say the least. Whether measuring a long cavity telescope or attempting to use a system on the production floor, the environment plays a major role in the performance of an interferometer. Vibration and air turbulence can be so severe as to prevent a traditional phase shifting measurement. While Zygo's GPI/Verifire systems provide the highest accuracy and performance available, standard phase shifting acquisition is often simply too slow to meet the challenges presented by an unstable environment.

Enter FlashPhase™

Zygo's answer to these challenging environments is a new acquisition method called FlashPhase™. Unlike our standard measurement methods where multiple frames of intensity are combined to produce a surface or wavefront map, FlashPhase™ extracts the phase information from just a single frame. Using a proven technique based on Fourier analysis of the intensity data, FlashPhase™ extends the capabilities of our laser interferometer systems allowing our customers to take phase measurements in harsh environments. Unlike other hardware based approaches for high speed acquisition, FlashPhase™ does *not* sacrifice the high end performance inherent in traditional phase shifting interferometry.

The technique, although computationally complex, is very fast on today's powerful computers and can be implemented on nearly any of our phase measuring interferometers in the field. In addition, Zygo's higher performance systems (GPI HS & Verifire AT), with their digital cameras, can be shuttered via MetroPro™ for data acquisition times that are a fraction of their standard 60Hz (16.663msec) camera frame rates. In fact, one of these shutter-able FlashPhase™ enabled systems can even be used *without* a vibration isolation table.

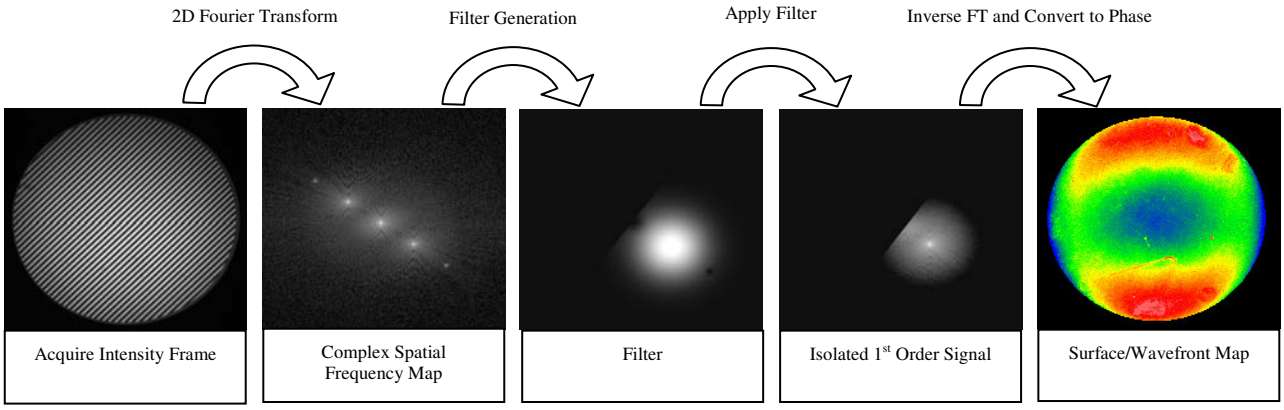
Why FlashPhase?

There are numerous techniques available for high speed phase acquisition and Zygo considered a number of them. However, there were three primary goals behind developing a high speed measurement technique. First, we wanted an affordable alternative to the more hardware oriented solutions available. Second, we wanted a solution that could upgrade existing systems allowing our customers to extend their investment. And finally, we did not want to sacrifice the high performance capability of our systems. Zygo has spent more than 30 years establishing itself as the worldwide leader in interferometry and many existing users that wish to take advantage of FlashPhase™ under certain application conditions will continue to demand the most from their Zygo interferometers. FlashPhase™ meets all of these demands in the form of a cost effective upgrade that allows the user to choose the new acquisition method when the need arises. Zygo is the only company that offers both capabilities (high precision & high speed) in one system.

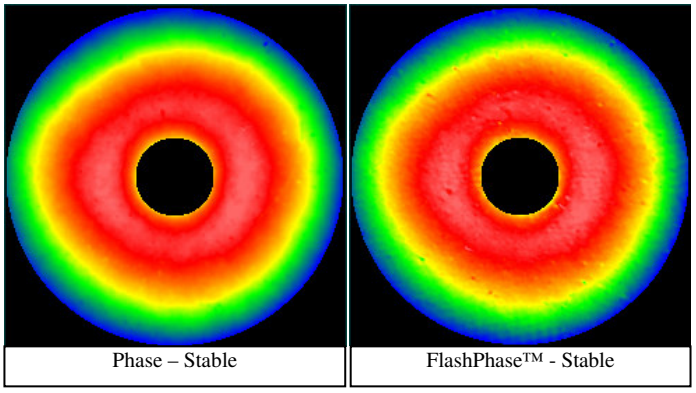
The Technology.

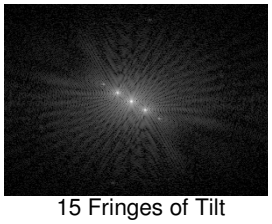
The fringe pattern obviously contains phase information of the surface or wavefront under test. While traditional "fringe center" analysis provides the ability to capture a frame quickly, it suffers from a lack of lateral resolution and phase precision, and generally does not meet the demands of most applications. Fourier transforms provide us with the tools necessary to extract high lateral and vertical phase information from a single frame.

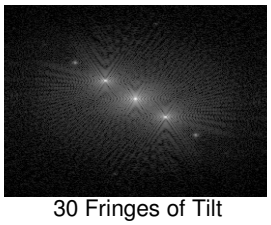
Once we capture the intensity information, we apply a 2D Fourier Transform and generate a complex spatial frequency map. The 1st order signal is isolated and an inverse 2D Fourier Transform is performed to extract the phase of each pixel on the map. We then convert to surface/wavefront height. This process is shown in the sequence of plots below. Thus, a relatively small number of high level mathematical steps combined with the computational power of today's computers provide the means to make very fast phase measurements in environments where traditional phase shifting interferometry is not possible.

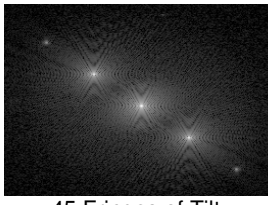


The correlation between FlashPhase™ and standard phase measurements is surprisingly good. The plots to the left show a comparison between phase shifting and FlashPhase™ measurements in both quiet and "noisy" environments. Both FlashPhase™ measurements are nearly identical to the "quiet" phase shifting measurement whereas the traditional method obviously suffers in the presence of vibration. Naturally, as with any interferometric measurement, there are numerous setup parameters (number of fringes, light level, vibration frequency, etc) and controls (shutter speed, filter selection, averages, etc) that will effect the data collection/analysis accuracy of the measurement. However, the default settings in MetroPro™ should provide reasonable results for each type of system enabled with FlashPhase™ and only require minor adjustments, if any, to achieve repeatable results.




15 Fringes of Tilt


30 Fringes of Tilt

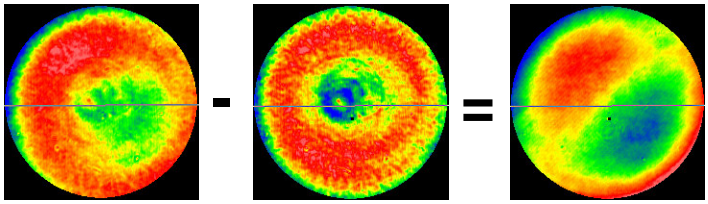

45 Fringes of Tilt

Error Correction

In order to extract the phase information from the intensity data, it necessary to isolate the 1st order spatial frequencies from the other orders (DC, 2nd, 3rd …). This is accomplished by inducing an amount of tilt in the aperture. This is what is referred to as "spatially separating: the phase information. The more tilt, the further the orders will be separated, making isolation of the 1st order signal easier and the measurement process more robust (see plots to the right). However, since interferometers are typically designed to measure on axis (i.e. null fringes) the necessary tilt can induce errors that must be corrected to achieve the highest accuracy measurements. The amount of correction necessary is a function of the zoom setting (if one is available), the speed of the transmission element, and the amount of tilt in the aperture. However, in many instances, such as large apertures (>12") should not require any correction in order to achieve reasonably accurate results ($< \lambda/10$).

Generating a correction file is a straightforward process that makes use of the System Error Subtraction capability in MetroPro. A correction file must be generated for each Transmission Element and each zoom setting. The following details the steps necessary to generate a correction file:

1. Set up the part to be tested
2. Adjust Zoom to desired setting
3. Insert reference element, keeping zoom fixed
4. Take a standard Phase measurement with zero tilt and save the data (e.g. PhaseNull.dat)
5. Adjust cavity tilt to the desired number of fringes across the aperture
6. Take another Phase measurement and save the data (e.g. PhaseTilt.dat)
7. Subtract the first measurement from the second and save the resulting data set as your correction file (e.g. Correction.dat). The plots below are an example of this process.

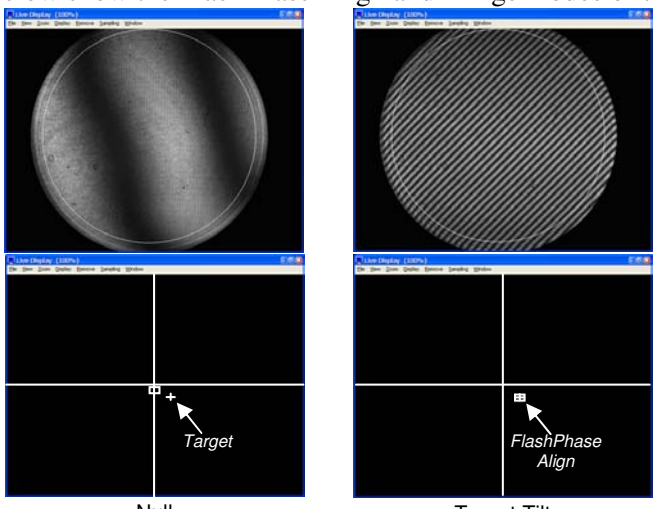


Phase w/Tilt | Phase @ Null | Correction File

Once generated for a particular part to be tested, that same correction file can be used for all subsequent measurements as long as the zoom setting is not changed.

Alignment Aid

The correction files have been used to show extremely good correlation between FlashPhase™ and standard phase measurements. However, in order to apply the correction file accurately, the amount and direction of the tilt must be the same for the test piece as used to generate the correction file. To make this easier, we've built in an aid to assist the operator with alignment. As part of the Live Display window, the software monitors the fringe pattern as the operator adjusts the tilt of the part (or reference) until the box covers the crosshair. The pictures below show the FlashPhase Align and Fringe modes of the Live Display:



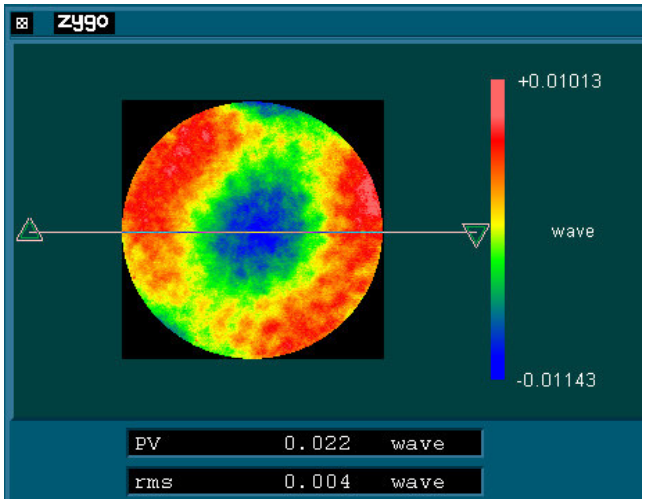
Null | Target Tilt

By using this aid, the user will get the accuracy and consistency expected from a Zygo instrument.

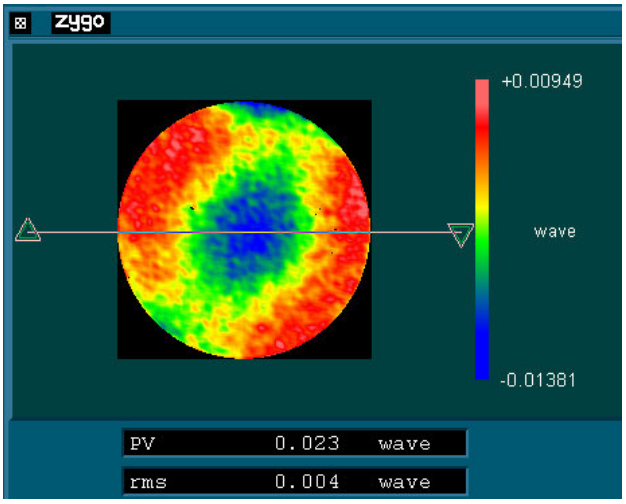
Conclusion

Historically, Zygo's interferometers have been reserved for stable environments such as Quality Control and R&D labs. This restricted the applications and usefulness of interferometry to quiet environments. FlashPhase™ now provides the means necessary to implement laser interferometry in a variety of new applications. Zygo interferometers can now be used on the production floor, installed for in situ testing, and provide phase measurements on very large aperture systems without the need for a phase modulator.

FlashPhase™ Specifications



Standard Phase Measurement



FlashPhase Measurement

General Specifications

Instrument Requirements	Zygo interferometers running MetroPro™ on a late generation PC platform
Acquisition Method	Spatial Carrier Fringe
Measurement Uncertainty(1)	λ/20
Camera Array	System Dependent Up to 1024 x 1024
Part Alignment	
Nominal:	Quick Fringe Acquisition System (QFAS) with twin spot reticle on Live Video Display window
Precision:	FlashPhase Alignment Aid on Live Video Display window
Part Viewing	Live Video Display on computer monitor (no external monitor)
Software	ZYGO MetroPro software running under Microsoft® Windows 2000 Professional

Performance

Acquisition Rate (camera dependent)	30 or 60 Frames per Second
Minimum Exposure (camera/zoom dependent)	GPI XP/XPHR: 16.667 msec GPI HS: 1 msec @ 1X Zoom Verifire AT: 1 msec @ 1X Zoom (Faster exposures available)
RMS Repeatability (2)	λ/2000
RMS Precision (3)	λ/300

Software Features

Live Video Display	Live Fringe, Live Phase Map, FlashPhase Align
Graphics (subset)	Filled Plot, Oblique Plot, 3D Map, Slope Plot, 2D Profile with Inspectors
Results (subset)	PV, RMS, Power, Astigmatism, Coma, Spherical Aberration, Zernike Polynomial Coefficients,
Other Functions	Data Masking, Reference Removal, Phase Averaging

Options

1 Measurement Uncertainty specification assumes an error correction phase map is subtracted from FlashPhase™ measurement.

2 Quoted repeatability is for 10 measurements of the same cavity, with 16 averages per data set. The specification represents the 1σ value.

3 Quoted precision is the average rms of 10 data sets with a reference measurement subtracted. Each data set includes 16 averages and the reference measurement is the pixel-by-pixel average of 10 measurements.