FRINGE INTERPRETATION
… a brief Tutorial

by Gordon Graham.

GRAHAM OPTICAL SYSTEMS

9530 Topanga Canyon Blvd.,
Chatsworth, California 91311
(818) 700-1263
WEB: www.grahamoptical.com

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Analysis of Surface Fringes

Volumes have been written about fringe interpretation and the subject can be treated as either an art or a science — it is a little of both. The simplest way to approach the matter is to provide the operator of an interferometer with some examples of various fringe patterns, also known as "interferograms" together with a clear description of their meaning.

A more analytical method is required in many cases and an attempt will be made to provide a very simplified and abbreviated demonstration of the techniques involved. The interferograms and drawings presented are intended to familiarize the reader with the methods of fringe interpretation.

Topographical Maps of a Surface

One can think of an interferogram as a type of topographical map of the surface, only instead of the lines representing surface levels in feet, the contour lines are separated in height from each other by one-half wavelength of light. For interferometers that use a Helium Neon Laser, this wavelength is 0.6328 micron.

So one-half of a wavelength is 0.3164 micron (~ 12.46 millionths of an inch). Thus, at the position of each contour line or "fringe" the surface is at a level of 12.46 millionths of an inch above or below the fringe adjacent to it.

When a surface is not very flat, there are a lot of fringes — just as one sees the tightly packed contour lines surrounding a mountain or a steep valley. When examining this kind of surface, the tilt-table of the interferometer is simply adjusted to achieve the minimum number of fringes attainable. This really just means adjusting the tilt of the test piece until it is as parallel as possible to the interferometer's reference surface.

These fringes are then counted, thus yielding some number such as "flat to 4 fringes" or "flat to 2 fringes per inch"

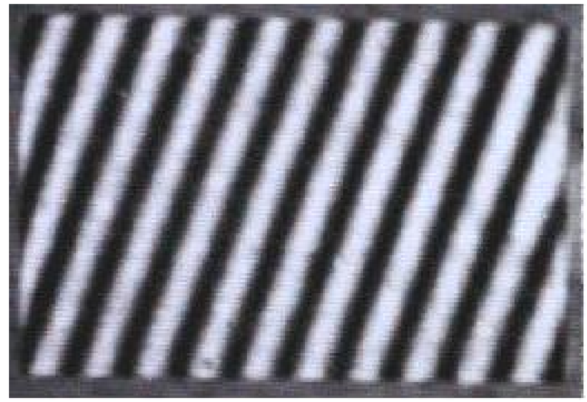

Figure 1
Interferogram of a very flat surface …straight, parallel fringes.

On a topographical map, when the surface is very flat, such as the bottom of a shallow valley or plain, or on a plateau or mesa, the lateral distance between contour lines may be very large — indeed there may be only one contour line or perhaps no contour lines at all over an extended region.

This corresponds to a very flat optical surface which may be flat to a very small fraction of a fringe. In the interferogram shown in Figure 1**,** if the operator simply adjusts the interferometer tilt-table to reduce the number of fringes to as few as possible, there would not be **ANY** visible fringes at all! The surface would appear either all black (a black fringe) or all white (a white fringe) but without any fringe "pattern". In order to resolve this dilemma we must have a way of measuring such "fractional fringes". The method is called "Fringe Splitting"

"Fringe Splitting"

Suppose that a surface is flat to about ¼ of a fringe. Adjusting the tilt table to make the test surface parallel to the interferometer's reference surface would result in the interferogram being either all black or all white, and would not permit any precise measurement.

In Figure 2 at the right, we see a number of curved fringes with some lines drawn through them. The two red lines are drawn to be tangent to the center of two adjacent fringes. The green line is drawn to pass through the center of one of the fringes where it intersects the edge of the test piece.

The arithmetic is simple. The distance between the two red lines is the width of one fringe which we call "X"(here measured to be 5.02 in arbitrary units) and the distance from the center of the lower fringe to the green line we have called "Y" (here measured as 1.24)

The flatness of the test piece is then:

Y/X = 1.24/5.02
= 0.247 fringe ~ a quarter fringe.
= 0.078 micron
= 3.07 millionths of an inch!

Not bad for measurement with a plain old ruler!

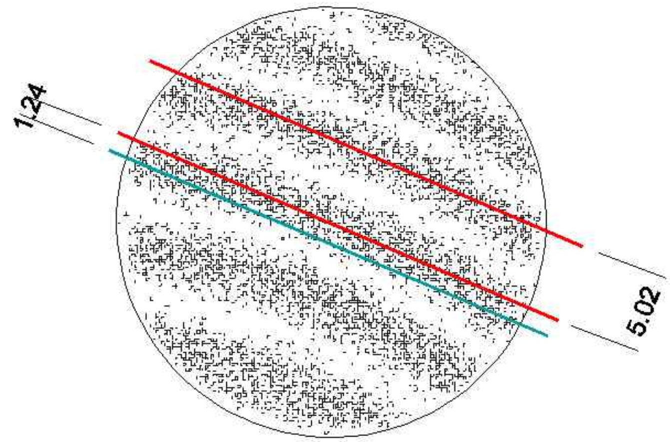

Figure 2

Just to illustrate another example, the flatness of the test piece shown in Figure 3 is:

Y/X = 1.93/3.74
= 0.516 fringe
= 0.163 micron
= 6.4 millionths of an inch.

For some requirements, flatness may be called out in waves. For others it may be in micrometers (also known as microns) nanometers or in microinches. A little calculation lets you manipulate these figures readily. As a handy reference on dimension conversion see the table on the next page.

Very Flat Parts
…Evaluation of "Straight" Fringes

When a part is very flat, to less than 1/5 fringe as shown above, the fringes are so straight and uniformly spaced, that it becomes very difficult to accurately measure the fringe pattern without computer analysis. Therefore, for the routine measurement of parts that are this flat, the use of a computer equipped interferometer with either **Static Fringe** or **Phase Analysis** software becomes a necessity if reliable, repeatable measurements are to be made.

Some experts are able to accurately determine the flatness of such parts without the use of a computer, but these individuals are rare, and often two such experts will not entirely agree on the flatness of a part. In addition, such evaluations, even if they are quite accurate, do not provide any hard numerical data that can be verified and documented.

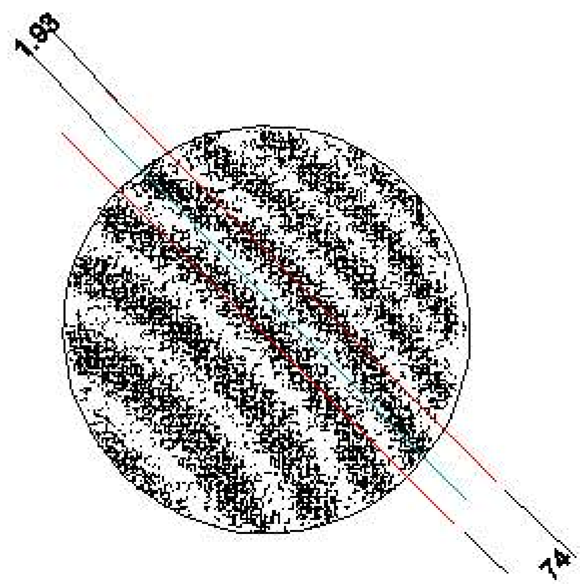

Figure 3

DIMENSION CONVERSION TABLE

English /Metric	1 inch =	1 microinch =	1 millimeter =	(Micron) 1 micrometer =	1 nanometer =
Inches	**********	.000001 inch	.03937 inch	.00003937 inch	.00000003937 inch
Microinches	1,000,000 microinches	*************	39370 microinches	39.37 microinches	.03937 microinch
Millimeters	25.4 millimeters	.0000254 millimeter	************	.001 millimeter	.000001 millimeter
Micrometers (Microns)	25,400 micrometers	.0254 micrometer	1,000 micrometers	************	.001 micrometer
Nanometers	25,400,000 nanometers	25.4 millimeters	1,000,000 nanometers	1,000 nanometers	************

If using a Fizeau Interferometer (with Helium-Neon laser operating at wavelength 632.8 nanometers) to measure a surface by reflection, the following table may be helpful

Waves/Metric Fringes/Metric	1 wave=	1 fringe = ½ wave =	¼ wave =	1/10 wave =	1/20 wave =
Nanometers	632.8 nanometers	316.4 nanometers	158.2 nanometers	63.28 nanometers	31.64 nanometers
Micrometers (Microns)	.6328 micrometer	.3164 micrometer	.1582 micrometer	.06328 micrometer	.03164 micrometer
Millimeters	.0006328 millimeter	.0003164 millimeter	.0001582 millimeter	.00006328 millimeter	.00003164 millimeter
Microinches	24.913 microinches	12.457 microinches	6.228 microinches	2.3913 microinches	1.2457 microinches

What if the fringes are concentric circles or other closed loops instead of lines or arcs?

Figure 4 shows an interferogram which consists of concentric fringes. Closed loop fringes indicate a surface that is either concave or convex. Simply looking at an interferogram, it is not possible to tell which.

Concave or Convex?

To determine which, the operator adjusts the tilt table so that the test piece moves upward (toward the interferometer) the fringes will always "roll downhill – just like water". This particular part was concave – i.e. when adjusting the tilt table toward the interferometer, the fringes rolled toward the center.

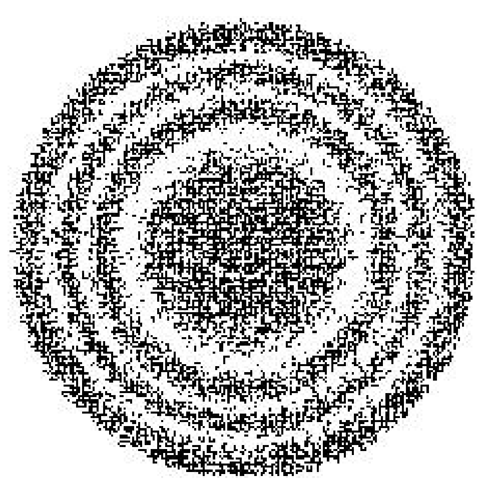

Figure 4
Interferogram of a part which is concave by 4 fringes (about 50 millionths of an inch)

General Procedure
Testing an optical surface using an interferometer.

These instructions presume that the operator is using a vertically oriented interferometer in which the test piece is placed upon the tip-tilt table. A typical interferometer, **Graham's Model 2V** is shown in Figure 5 at the right, with a small polished metal ring on the tip-tilt table. Note the fringes showing on the video monitor and the video printer. The Model 2V is a visual interferometer – the operator must interpret the interferogram without computer assistance.

(1) In operation, the table is adjusted to achieve a fringe pattern.

(2) If the fringes are more or less straight lines or arcs, the operator attempts to reduce the number of fringes to the minimum achievable.

(3) If the final adjustment shows a surface that "oscillates" between all black and all white, then the surface is flatter than one fringe.

(4) The operator then adjusts the tilt table to reveal a conveniently small number of fringes – say 4 to 10.

(5) The "fringe-splitting" technique outlined earlier is applied – either on the face of the video monitor on a hard copy produced on a video printer.

(6) If severely curved fringes are observed, the operator can evaluate the surface topography somewhat by observing the direction in which the fringes move when the tilt table is adjusted toward the interferometer.

For a concave surface feature, the fringes will pour down into any valley.

For a convex surface the fringes will flow down the outside of any hill.

Remember the simple rule:

Raising the tilt-table toward the interferometer causes the fringes to run downhill — just like water.

It is not uncommon on some surfaces to find both hills and valleys in a very complex topography as in Figure 7. Some are saddle-shaped and some are shaped like potato chips. Often such unusual topography can indicate the need to modify the lapping or polishing method being used.

Figure 5
GRAHAM'S Model 2V
FRINGE MITE
Visual Interferometer

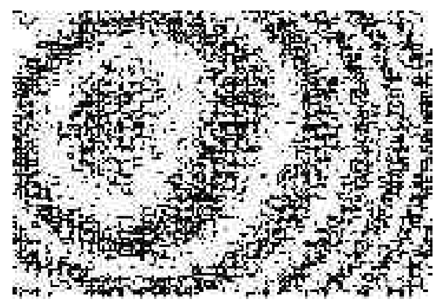

Figure 6
Interferogram of part with hill

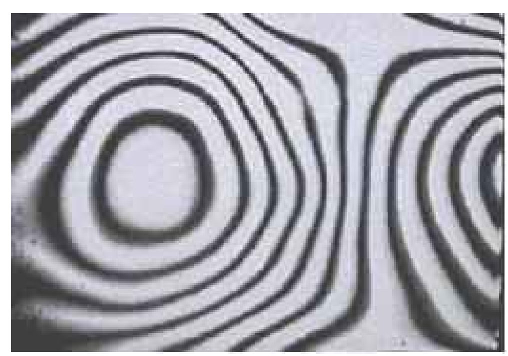

Figure 7
Complex surface – Hill and Valley

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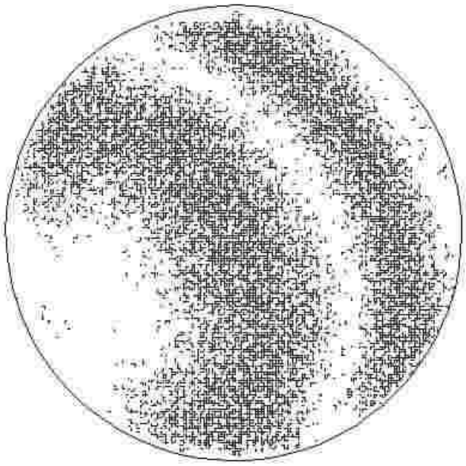

Figure 8
Interferogram of Part flat to 2 fringes ~ 25 millionths of an inch

Figure 9
GRAHAM'S Model 2VP "PHASE MITE"
Phase-Shifting Interferometer
Equipped with Durango
Universal Interferometry Software™
by Diffraction International Ltd.

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Lapped Parts Flat to a Few Fringes

These are the parts which are easiest to measure. The interferometer is simply adjusted to show the minimum number of fringes achievable, and then the fringes are counted. It's as simple as that.

If these parts are being evaluated using test flats, the part is brought into optical contact with the test flat and then the fringes are counted. The only problem here is that with a test flat, a certain amount of pressure is required to squeeze the air out of the gap. It is difficult to know when true optical contact has been made.

If the air gap is wedge-shaped because of a piece of dirt or lint, then more fringes will appear than there should be, and the part will be down-graded below its real quality. In many cases such parts may be rejected, even though they really do meet specifications.

On the other hand, if too much pressure is applied in order to produce optical contact, actual distortion of both the part and the test flat may result, and a bad part may pass inspection when it should have failed. The result is that even for these simplest of evaluations (surfaces that are flat to a few fringes) serious errors can be made using test flats, particularly in inexperienced hands, whereas an interferometer always gives the same measurement, and can provide hard-copy verification of the data!

There are so many factors involved in fringe interpretation, that it can, at times, be a very difficult task. Certainly for high precision measurements that are repeatable, flatness interpretation needs a helping hand.

This is where computer-assisted interferometers save the day!

The **Graham Model 2VP "PHASE MITE"** is an example of a Phase-Shifting Interferometer. It utilizes a computer and Durango Software. This very sophisticated Interferometry Software Program by **Diffraction International** permits the interferometer to make precision measurements of the surface and provides a number of revealing graphics of the surface profile – including 3-dimensional isometric plots **– no more guesswork about the shape of the surface!**

Interferometry Software

For highly precise and repeatable measurements of flatness, a computer evaluation of the interferogram is recommended. Two basic types of computer analysis are available: Static Fringe Analysis and Phase-Measuring Analysis,

Static Fringe Interferogram Analysis

In these systems, the Interferometer's CCD camera is connected directly to a "Frame Grabber" board in the computer. At the press of a button, all of the interferogram's imaging data is dumped into the frame grabber so that the computer can begin elaborate data processing of the fringe position and straightness.

Whereas with the simple approach described previously, we might make a flatness evaluation based upon the position and shape of 2 or 3 fringes, the Static Fringe Software looks at a hundred or more data points on the fringes and performs complex data reduction techniques to produce hard figures of rms flatness, peak-to-valley flatness, irregularity, etc. This permits the generation of elaborate graphical output of surface contour, showing 3-dimensional isometric plots, cross-sections, etc. Any basic interferometer with a CCD camera can be up-graded to perform Static Fringe Analysis at any time.

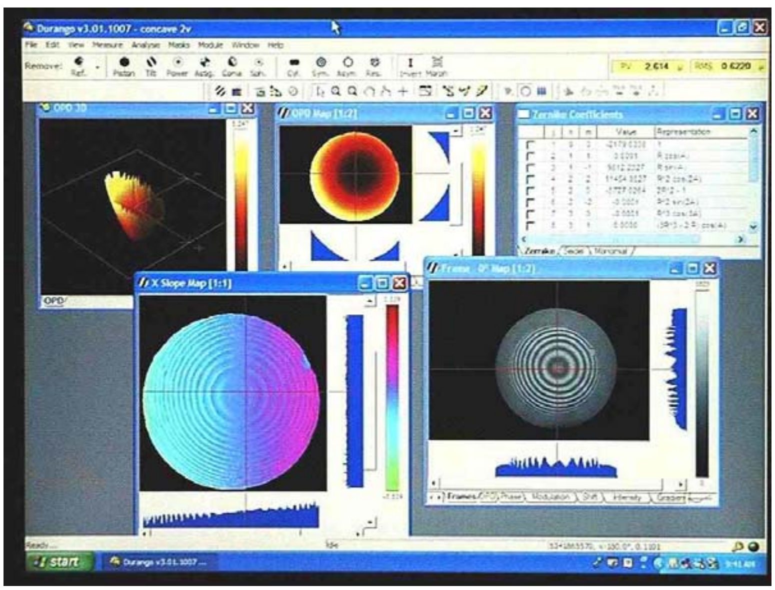

Figure 10

Typical Durango Screen
Showing Phase Analysis of Surface

Figure 9 is an example of several aspects of a typical Durango Phase Analysis of a surface with closed, concentric fringes. Colorful graphics show surface plots, dynamic cross-sections, 3-dimensional isometric plots (which can be animated) as well as numerical data, customized notes and Quality Control reports

Phase Measuring Interferogram Analysis

In Phase-Measuring (Phase-Shifting) interferometers, the frame grabber board captures five or more images of the interferogram, with the fringes in each image being shifted a distance of 1/4 wavelength of the laser source. This is accomplished by means of a piezoelectric transducer which actually moves either the reference flat or the test part in a number of small steps, each 1/4 wavelength long. (Other phase steps may also be chosen.)

The mathematical reduction of this data looks at 60,000 data points or more (depends upon size of sample) on the interferogram, yielding extremely high accuracy and repeatability, with a number of advantages over the Static Fringe method. Since special equipment is required to perform Phase-Measuring, it is not always possible to up-grade existing interferometers which are not properly equipped to handle the additional hardware required.

Static Fringe or Phase-Measuring?

The choice between these two types of systems is dependent on a number of factors:

(1) Phase-Measuring Interferometers are substantially more expensive than Static Fringe Systems

(2) Although the same type of data and graphic output is provided by both systems, the Phase-Measuring Interferometer will provide higher accuracy and greater repeatability.

With a Static Fringe Interferometer, it is necessary to place a synthetic aperture around the part being measured as well as a synthetic obscuration about any holes in the part. This is required to tell the software "where not to look." Placing these apertures and obscurations is the responsibility of the operator, and can be a slow and nearly impossible task with some complex test pieces.

With a Phase-Measuring Interferometer, this is unnecessary, since it looks at phase data, it never requires a synthetic aperture or obscuration. Not only does this save a lot of time and effort, but it also guarantees a higher level of accuracy.

Since the Static Fringe Interferometers do not change the distance between the test piece and the reference surface, it is not possible to tell the difference between concave and convex. (Remember our prior discussion: when the test piece is moved toward the reference surface, the fringes run downhill — just like water.)

Phase-Measuring Interferometers do not have this problem. Since they move either the test piece or the reference flat, the system can determine whether the test piece is concave or convex, i.e. it can tell a hill from a valley.

Graham Optical Systems offers both Durango Static Fringe and Phase-Measuring Software with its interferometers including our **LAZER GRAZER** grazing incidence interferometers, which are used for the measurement of semi-matte and matte surfaces. All non-phase **Graham** Interferometers can be upgraded to full phase shifting operation.

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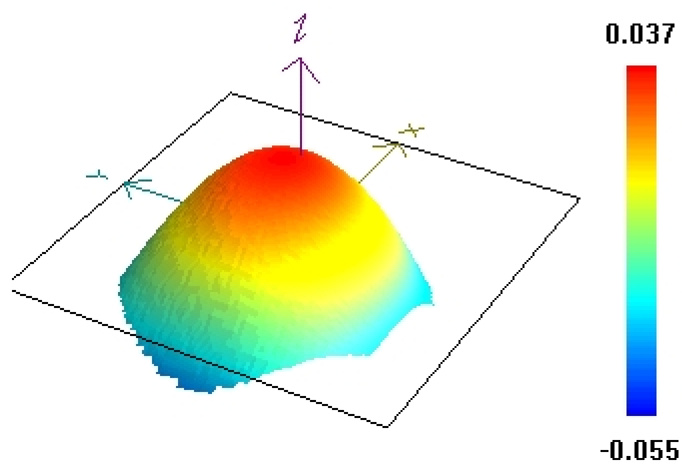

Durango **3-D Plot of Convex surface**

We invite you to visit our web site for other tutorials that we hope you will find informative.