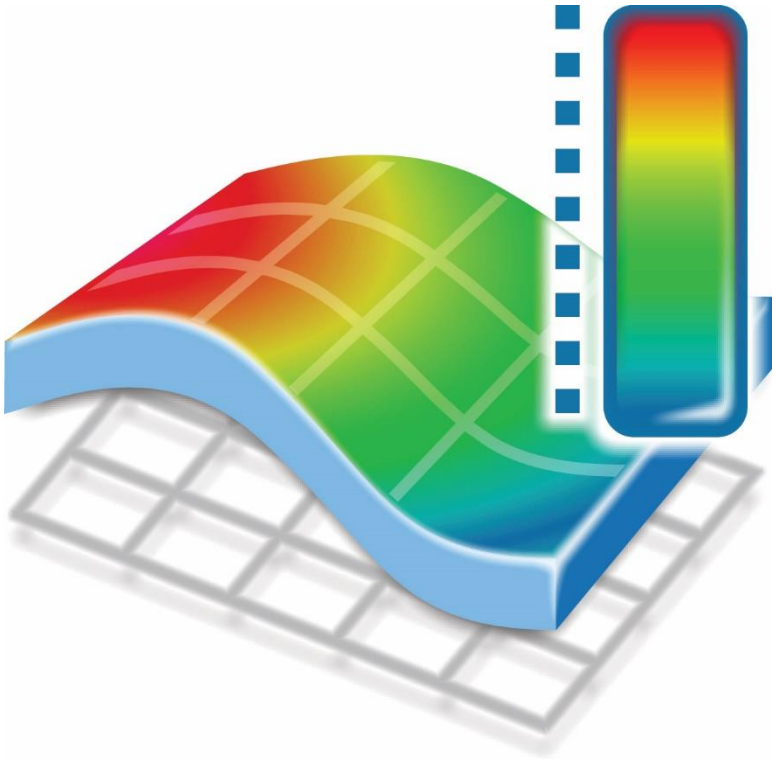
akrometrix

Surface Analysis



User Manual

Akrometrix Proprietary Information

No reproduction, adaptation, or translation without prior written approval.

Warranty

The information contained in this document is subject to change without notice.

Akrometrix makes no warranty of any kind with respect to this information.

Akrometrix shall not be liable for any direct, indirect, incidental, consequential, or other damage alleged in connection with the furnishing or use of this information.

Trademark Credits

Microsoft®, Windows®, Excel®, Notepad®, and MS Paint® are registered trademarks of Microsoft Corporation.

TherMoiré® is a registered trademark of Akrometrix, LLC.

Contents

1 Introduction 5
1.1 Overview 5
1.2 Warnings and Notes 6
1.3 Technical Support 6
2 Loading Measurement Data 8
2.1 Starting the Program 8
2.2 Loading Measurement Data 8
2.3 Working with the Phase Image 8
2.4 Working with Displacement Data 11
2.5 Saving Displacement Images 23
3 Modifying Measurement Data 24
3.1 Setting the ROI 24
3.2 Masking a Phase Image 25
3.3 Cropping a Phase Image 31
3.4 Phase Amplitude Thresholding 31
3.5 Partitioning a Phase Image 33
3.6 Smoothing a Phase Image 40
3.7 Rotating a Phase Image 41
3.8 Shifting a Phase Image 41
3.9 Undoing a Phase Image Modification 42
3.10 Saving Phase Images 42
4 Analyzing Measurement Data 43
4.1 Analysis 43
4.2 The Options Window 43
4.3 Reference Plane – Rotation 46
4.4 Reference Surface – Relative Displacement 47
4.5 Reference Surface – Grating Compensation 49
4.6 Unwrapping Parameters 51
5 Displaying Results 57
5.1 Graphical Output – 3D Surface Plot 57
5.2 Graphical Output – 3D Contour Plot 61
5.3 Graphical Output – Default Chord Plots 61
5.4 Graphical Output – Custom Chord Plots 63
5.5 Numerical Output 65
5.6 Gauge Output 65
6 Interface Analysis 66
6.1 Orientation and Registration using IA Metadata 66
6.2 Offset Methods 67
6.3 One-Off Interface Analysis 70
6.4 Batch Interface Analysis 73
6.5 Gauges 78
7 Batch Processing 79
7.1 Batch Processing 79
7.2 Batch Analysis 80
7.3 Batch Masking 90

7.4 Batch Rotation 94
7.5 Batch Cropping 96
7.6 Batch Edit XY Orientation 98
7.7 Batch Convert 99
7.8 Batch Feature Detection 100
8 Batch Reporting 102
8.1 Grouping by Metadata fields 102
8.2 Selecting ROI's 110
8.3 Choosing Report Layout Settings 111
9 Manual Reporting 117
9.1 Adding Page Contents 118
9.2 Editing a Report 118
9.3 Saving the Report 119
10 File Finder 120
11 Troubleshooting 122
11.1 Failure to Correctly Interpret the Phase Image 122
Appendix A Miscellaneous Information 124
A.1 File Formats 124
A.2 Keyboard Shortcuts 125

1 Introduction

1.1 Overview

Surface Analysis is a program designed to analyze and display the results of shadow moiré and fringe projection measurements produced by Akrometrix warpage measurement systems. The program typically resides on the measurement system computer. If additional site licenses are purchased, **Surface Analysis** may also be installed as a stand-alone application on other computers, offloading analysis tasks from the measurement system. This manual is intended for use with Akrometrix Studio 9.0.

The analysis of interferometric data from shadow moiré and fringe projection systems is a rich and complex subject. The main text of this manual emphasizes the operation of the **Surface Analysis** program. The principles of interferometric techniques and analysis will be discussed in **Akrometrix Optical Techniques and Analyses 101** (**AOTA101**). This paper should be read first by users unfamiliar with these techniques.

The output of the data acquisition program and thus the input of the **Surface Analysis** program is an Akrometrix-defined file with the extension *.akx_phase or *.akx_disp (displacement images). These files can contain measurement and reference data as well as some measurement parameters and conditions. **Surface Analysis** converts data from the *.akx_phase and *.akx_disp file into height data, and if required, Akrometrix gauges.

The main analysis functions on shadow moiré acquired data in **Surface Analysis** are based on the phase image in the *.akx_phase file. A phase image is a two-dimensional grayscale image (computed from several intensity source images) containing a value at each pixel related to the surface height at that location. Many of the options available in the **Surface Analysis** program originate from two challenges in phase image analysis.

- First, the phase data must be analyzed as a whole and errors due to poor quality data in one region of the surface can affect the results in other regions. The *Smoothing*, *Partitioning, Amplitude Threshold, Unwrapping Parameters,* and *Masking* functions allow bad data to be smoothed or excluded from analysis.
- Second, the surface contour does not have an absolute frame of reference. The *Rotation*, *Grating Compensation*, and *Reference/Relative* functions allow the user to define the reference plane in a way most useful for understanding the experimental results.

A second group of options control the display and output of experimental results. **Surface Analysis** provides a suite of display formats, which can each be further customized to the user's preference. In addition, the displacement data can be exported in tabular form for plotting or further analysis by other software packages.

Finally, several batch and report tools allow repetitive functions to be automated and large amounts of data to be summarized:

- **Batch Analysis** allows the user to quickly analyze a set of related measurement data (e.g. the same sample at different temperatures)

- **Batch Masking** allows the user to quickly mask more than one phase or displacement image.
- **Batch Rotation** allows the user to quickly rotate more than one phase or displacement image.
- **Batch Cropping** allows the user to quickly crop multiple regions of interest from more than one phase or displacement image.
- **Batch Edit Metadata** allows the user to edit metadata such as Pin1 location and Measured Side on a phase or displacement image.
- **Batch Convert** allows the user to convert displacement files back into phase images
- **Batch Feature Detection** allows the user to apply a custom mask based on detected features in a phase image
- **Batch Interface Analysis** allows the user to analyze and produce large amounts of dual surface or gap plots
- **Create Report** allows the user to quickly summarize and report on large quantities of single surface warpage data and plots
- **Manual Report** recreates the legacy Report Generator application for use in creating simple 6-up image reports
- **File Finder** allows the user to search for phase or displacement files in a given folder that meet certain metadata or filename criteria

1.2 Warnings and Notes

1.2.1 Warnings and Notes in this Manual

Warnings and Notes are marked throughout the manual with these icons:

Figure 1.1 Warning Icon

Figure 1.2 Note Icon

Warnings are specific health hazards for the operator or potential sources of system damage. Notes highlight system limitations or automatic responses that may require corrective action by the operator for successful operation.

1.3 Technical Support

Akrometrix	404-486-0880	support@akrometrix.com
2700 NE Expressway	404-486-0890 (fax)	http://www.akrometrix.com
Building B, Suite 500		
Atlanta, GA 30345		

When contacting Akrometrix, please provide the system serial number, the version numbers of the Akrometrix software being used, a description of the problem or question, and contact information for reply. If the question concerns a particular measurement or analysis, please provide electronic copies of the *.akx_phase or *.akx_disp files, final results, and a description of data acquisition and/or analysis conditions. If the problem concerns changes or failure in general system operation, please describe any events or system modifications that occurred immediately before the problem arose.

2 Loading Measurement Data

2.1 Starting the Program

The **Surface Analysis** program can be started in four different ways:

A. Right click on the phase or displacement image in Surface Measurement and choose **Open in Surface Analysis…**.

B. Double-click on a valid *.akx_phase or *.akx_disp file

C. Launch the **Surface Analysis** executable file directly from its shortcut (e.g. via the Start menu)

D. Click the **Surface Analysis** button listed on the Akrometrix **Studio Manager** bar on the left side of the screen.

Note: Only one instance (copy) of the software can run at a time; subsequent calls to the program will activate the open instance.

2.2 Loading Measurement Data

Once the **Surface Analysis** program starts, a GUI (Graphical User Interface) frame will appear. The contents of the display frame depend on how the application was launched:

A. If called from the measurement software via clicking on a phase image, the current phase or displacement window from the data acquisition program is shown.

B. If an *.akx_phase or *akx_disp file was double-clicked, the phase or displacement image contained in the selected file is shown.

C. If the EXE is launched from a shortcut or **Studio Manager**, no image is shown and the user needs to select a file to open.

New measurement data files can be loaded into memory with the **File→Open** menu item. A standard **Open** dialog box appears, prompting the user to select a valid *.akx_phase or *akx_disp file. Multiple files can be opened at one time by highlighting multiple selections using the Shift or Control keys. Phase images and displacement images can also be dragged and dropped into the Surface Analysis program in order to open them.

Note: Surface Analysis can be configured to analyze the image and display results immediately upon opening the *.akx_phase file, using the **Tools→Options…** menu item. See **Section 4.2**

2.3 Working with the Phase Image

An *.akx_phase file may contain a variety of information such as measurement data (phase images, intensity images, etc.), reference data, as well as measurement parameters and conditions. When the *.akx_phase file is loaded, all the information in the file is loaded in memory. For display purposes, only the phase image will be shown in the

GUI of the **Surface Analysis** program. Modification (**Section 2.4.7**) and Analysis (**Section 4**) on the measurement data will be mainly applied to the phase image and any associated reference data that exist.

2.3.1 Resizing a Phase Image

The phase image window may be resized by clicking and dragging on any edge or corner. The image in the window can be zoomed by using **Ctrl+** or **Ctrl-** (**Figure 2.1** and **Figure 2.2**). Each action doubles or halves the size of the phase image.

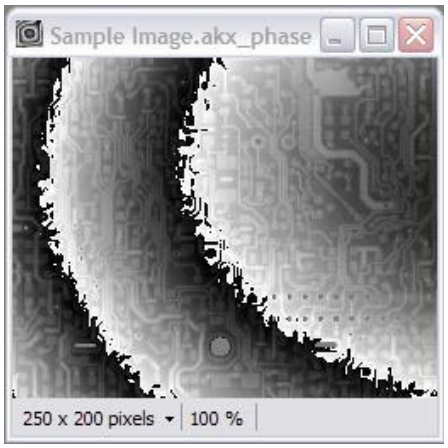


Figure 2.1 Phase Image 100% Magnification

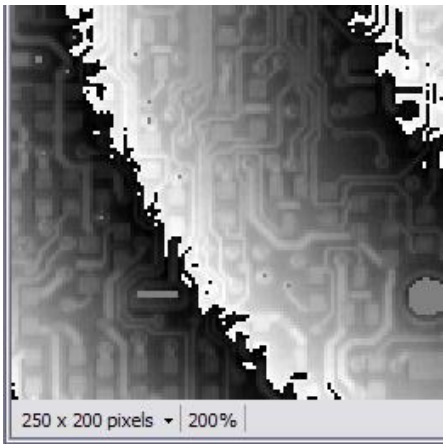


Figure 2.2 Phase Image 200% Magnification

2.3.2 Data Information

When a phase image is displayed in **Surface Analysis**, the image size and magnification percentage are shown on the status bar located at the bottom of the image (**Figure 2.1**).

2.3.3 Edit Metadata

Metadata for an individual phase image can be changed by right clicking on a phase image and going to **Edit Metadata**. For further information on metadata see **Section A.1.1**

Figure 2.3 Individual Edit Metadata Window

2.3.4 Measurement Information

In addition to the information described in **Section 2.3.2**, the measurement metadata can be displayed by right-clicking on the image and choosing **Properties…** (**Figure 2.4**).. In the Properties window, information about the intensity images, phase image, and grating can be found, along with many other metadata fields.

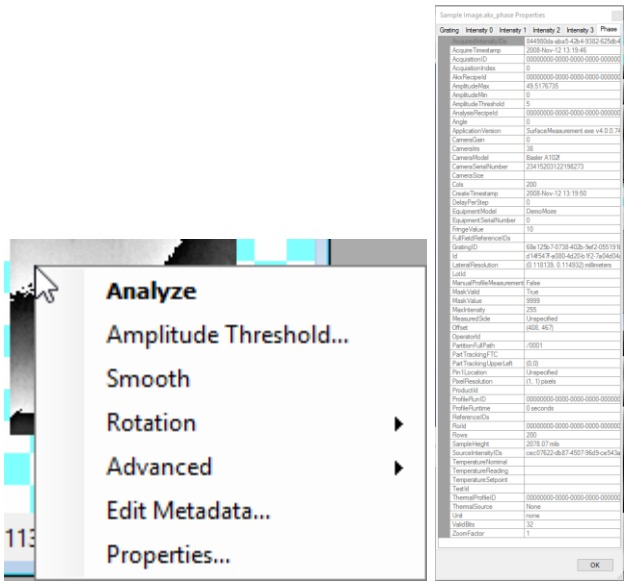


Figure 2.4 Displaying Measurement Metadata

2.3.5 Assigning Physical Size

Surface Analysis (and the TherMoiré measurement system in general) has no internal means of knowing the physical ROI (Region of Interest) size, but physical dimensions can be assigned by the user. Click the "Image Size" area on the status bar at the bottom left of the phase image. Select **Assign Size…** from the pull-up menu (**Figure 2.5**). In the Physical Size window, assign the unit as inches or millimeters, then enter the Width and Height of the image and click OK.

After physical dimensions have been assigned, the user can choose whether X and Y axes are displayed in pixels, inches or millimeters using the same pull-up menu on the status bar. The selected unit will appear on the X and Y axes of all graphs created after analysis.

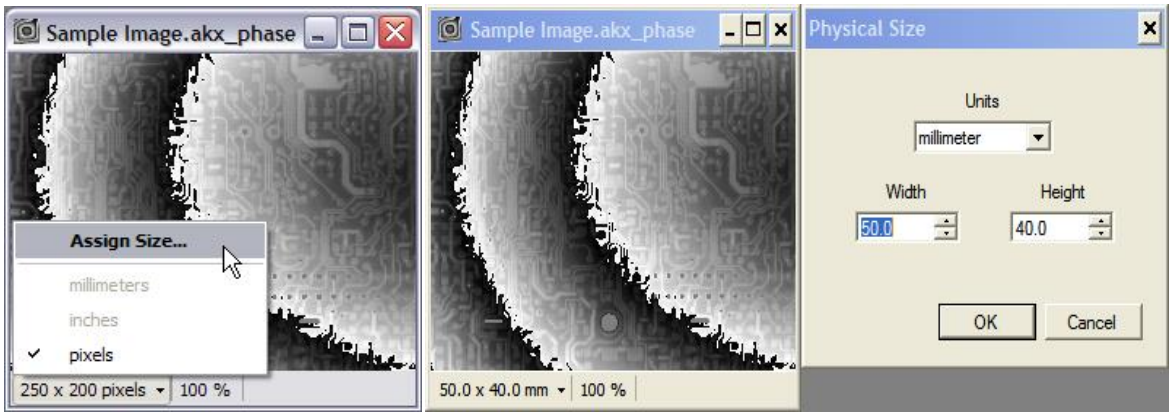


Figure 2.5 Assigning Physical Size for a Phase Image

Note: Physical dimensions are required for Compensation (**Section 4.4.2**) and calculation of the gauges Bow, Twist, DTA, and ROC (See **Akrometrix Optical Techniques and Analyses 101**).

2.3.6 Showing Surface or Intensity Images

Phase images have fringes across the whole field, hiding features on the sample surface. If the user wishes to make masks, partitions, or chords on the surface or intensity images, they can be shown by right-clicking on the phase image and selecting **Advanced→View→Surface Image** (or, alternatively, any one of the 4 intensity images). The image can also be quickly changed without the context menu by using the keyboard shortcuts **P**, **U**, **S**, and the numbers **1-4**. The currently viewed image can be saved to disk in by selecting **File→Save Image…** or **Ctrl+I**.

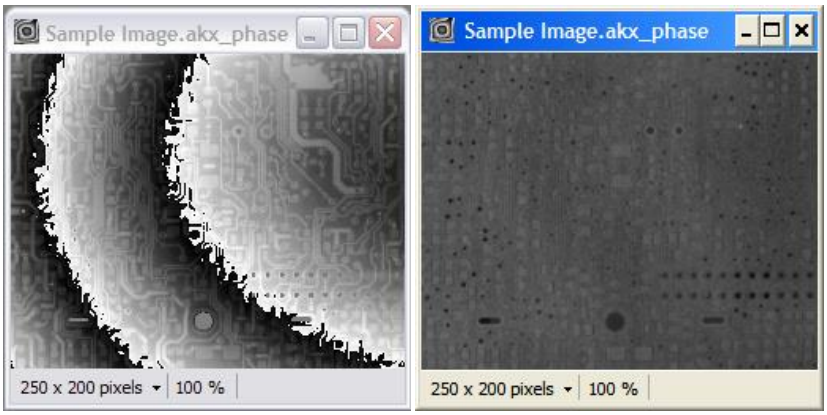


Figure 2.6 Phase and Surface Image Views

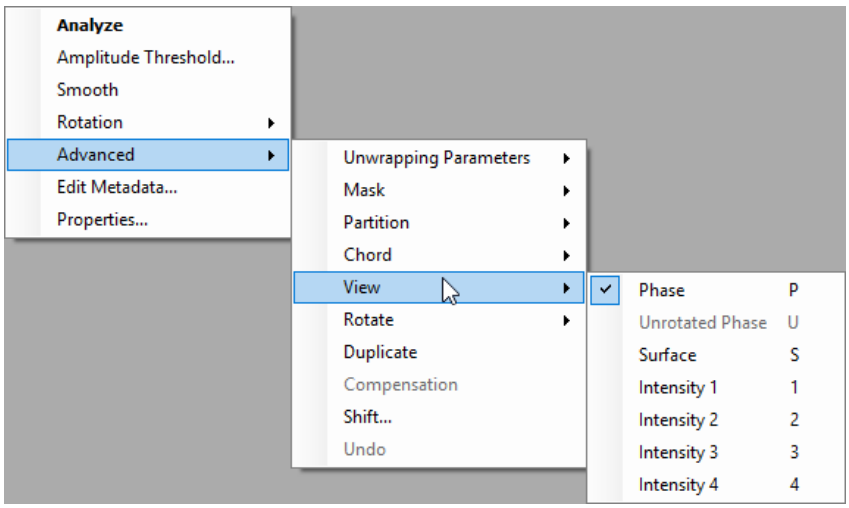


Figure 2.7 Menu Command for Showing Surface or Intensity Images

2.4 Working with Displacement Data

When an *.akx_disp image is loaded in Surface Analysis, a different window type is created as shown in **Figure 2.8**.

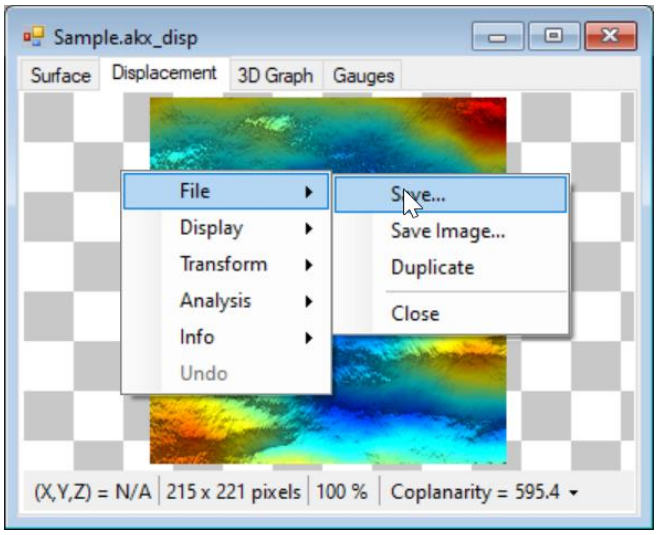


Figure 2.8 Loaded Displacement Window

This window shows the displacement data, average surface image, 3D graph, and gauge results on one tabbed interface. The interaction with this window happens via context menu, just as with the phase image window. There is now a File entry for saving the data in either its original format or as an image. The data can also be duplicated or closed from this menu item. Along the bottom is a status bar showing mouse cursor coordinates, overall dimensions, zoom setting, and gauge information.

This window can be resized by clicking and dragging on any edge or corner. The data can be resized using **Ctrl+** or **Ctrl-** or by scrolling the mouse wheel. Either option increases or decreases the size of the displayed data by 25%.

Other functions present in the phase image window are rearranged in this window to accommodate new functionality. The organization is described in the following sections.

2.4.1 File

Save…	Saves the data in *.akx_disp format
Save Image…	Allows display window to be saved in graphical format (*_3D.png or *_3D.jpg).
Duplicate	Makes a copy of the current displacement window in memory.
Close	Closes the displacement window. Prompts to save if any changes are detected.

2.4.2 Display

Zoom	Allows a reset of the image zoom that has been changed by the mouse wheel.
Z-Axis	Allows the Z-Axis units to be changed between microns and mils as well as to change the Z-Axis scale.

XY Size	Allows the X and Y data dimensions to be mapped to physical dimensions in either mm or inches.

2.4.3 Transform

Detect Features	Allows the user to filter data based on pattern recognition for specific features. See **Section 2.4.7**.
Mask	Allows the data to be masked. Contains all the same functions as described for phase images in **Section 3.2**, with the addition of "Z-Range…", which is unique to displacement data and described in **Section 2.4.8**, and "Via Phase Amplitude Threshold…", which is described in **Section 2.4.10**.
Smooth	Allows the user to apply either a default smoothing function to the 3D data or a custom one. The default smooth can be repeated multiple times. See **AOTA101** for more information.
Plane Rotation	Allows the user to change the data rotation as in **Section 4.3**.
Fit Data…	Opens a dialog where a polynomial fit can be calculated based on the data set. See **Figure 5.2**. Alternatively, if physical dimensions are assigned to the phase image, a spherical fit can be calculated.
Subtract	Displays the relative displacement data calculated by subtracting a selected 3D data from the current 3D data in a new window. See **Section 4.4.2**.
Rotate	Allows the data to be rotated about its Z-axis as in **Section 3.7**.
Shift…	Allows the data to be shifted in its plane as in **Section 3.8**.
Invert	Inverts Z data

2.4.4 Analysis

Step Height	Allows the user to define two ROIs and calculate the height difference between them. See **Section 2.4.9**.
Partition	Shows the same commands as under the **Advanced→Partition** menu for phase images, except for Array. See **Section 3.4**.
Chord	Shows the same commands under the **Advanced→Chord** menu for phase images. See **Section 5.4**.

Interface Analysis	Brings up a list of open *.akx_disp images for showing surface on surface plots from Interface Analysis. See **Section 6**.
SOFC	Displays a window containing all Second Order Fit Coefficients used to calculate a 2nd order polynomial fit for the surface. As of Studio 8.5, this list also includes the coefficient of determination, denoted R^2 (R squared).

2.4.5 Info

Allows the user to edit metadata and access the properties window associated with the displacement image. In the Properties window, information about the intensity images, phase images (if any), and grating (if any) can be found, along with many other metadata fields.

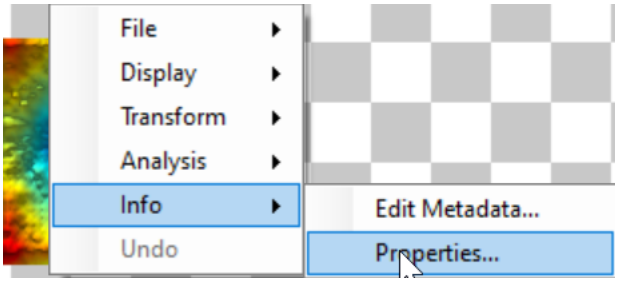


Figure 2.9 Info Menu on Displacement Image

Figure 2.10 Edit Metadata Dialog on Individual Displacement Image

2.4.6 Undo

Allows the user to undo the most recent change.

2.4.7 Feature Detection

Feature Detection allows the user to create a custom mask by searching for certain regions in the displacement data. This function is modal. Selecting it from the Transform context menu brings up a feature ROI whose default shape is an ellipse (**Figure 2.11**) and the Feature Detection window (**Figure 2.12**). While the Feature Detection mode is active, tab switching in the displacement image window is disabled. This mode can be turned off by pressing **Esc** or selecting Cancel from the context menu.

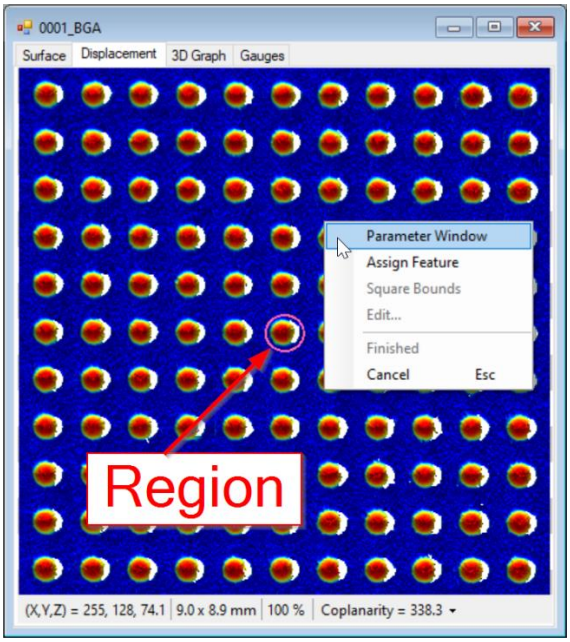


Figure 2.11 Feature Detection Region

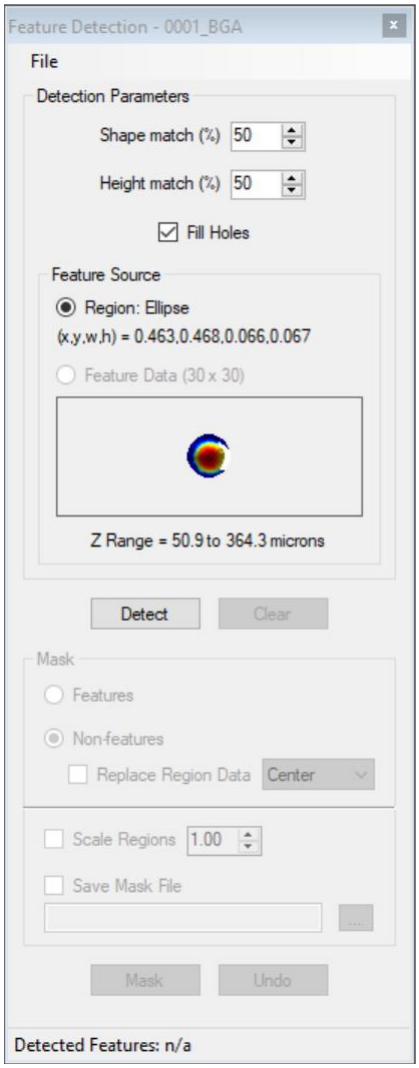


Figure 2.12 Feature Detection Parameter Window

The Feature Detection process consists of two steps: detection and masking. The parameter window and context menu are divided accordingly. During detection, a single ROI is set up with matching parameters and all features are found that fit that shape. During masking, the detected ROIs can be edited to create a final mask, which may then be burned or saved. Current Detection Parameters can be saved from the **File** menu and loaded again in another one-off displacement window or in batch processing.

Switching between the Feature Detection steps is accomplished using the **Detect** and **Clear** buttons in the middle of the Parameter Window. **Detect** scans the image for instances of the feature in question, creating an ROI around each one that can be edited in Masking mode. **Clear** deletes all ROIs but the original one, returning to the detection step.

The two versions of the Feature Detection context menu are shown in **Figure 2.13** and **Figure 2.14**. They are mostly the same, but since the mask step can have multiple ROIs, there are more editing options.

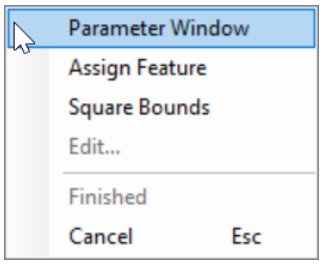


Figure 2.13 Feature Detection Context Menu - Detection

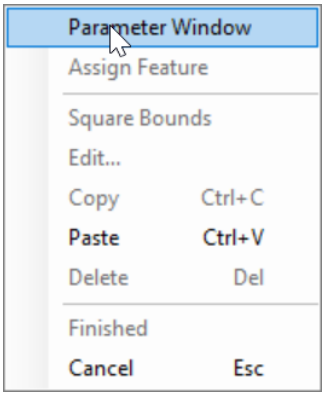


Figure 2.14 Feature Detection Context Menu - Masking

- **Parameter Window** opens the window or brings it to the front, depending on whether it is already open
- **Assign Feature** assigns the Region source from the current selected area
- **Square Bounds** equalizes the horizontal and vertical dimensions of the ROI as the shorter value of the two
- **Edit** brings up the ROI Editing window described in **Section 3.1**.
- **Copy** (**Ctrl+C**) copies the selected ROI into memory.
- **Paste** (**Ctrl+V**) places an instance of the copied ROI at the cursor location.
- **Delete** (**Del**) deletes a single ROI.
- **Cancel** (**Esc**) exits out of Feature Detection without making any changes to the displacement image, although the Feature Detection settings will be remembered as long as the same instance of the *.akx_disp file is open.
- **Finished** exits Feature Detection when the user is done, leaving applied masks in place. This menu item is always visible but only active at the end of the Feature Detection process.

Note: Mask ROIs start out as copies of the Detection ROI but can be independently edited. Everything in **Section 3.1** applies to Feature Detection ROIs.

In the top half of the Feature Detection Parameter Window (**Figure 2.12**), detection parameters can be set based on the feature detection region (**Figure 2.11**). This is the initial ROI which appears when Feature Detection is opened. Its location and size can be edited like any other ROI. **Shape Match** and **Height Match** control the degree of accuracy in exact shape and size required to find matches. Higher numbers will typically result in more features found. **Fill Holes** fills all mask regions with fabricated data based on the neighboring edges. Note that this option does not affect the final output, only the input dataset for the detection process, so there will be no visual indication on the 3D data that anything has changed. For a typical solder ball detection application, having this checked will improve the number and accuracy of features found.

If previous detection has been performed and saved via the **File** menu, **Feature Data** may be used by loading in a feature detection file (*.akx_featuredetection). A preview of the displacement data to be found is shown in the center of the parameter window once the file is loaded.

In the mask step, the user edits the ROIs on the displacement image and sets mask parameters in the Parameter Window. These include the choice of whether Feature or non-Feature data is masked. If Non-feature data is to be masked, then the found features can be replaced with a single value, the maximum, minimum, or the value of the center pixel in each region. This is particularly useful when finding solder ball peaks. **Scale Regions** increases or decreases their size when masking and **Save Mask File** converts the results into a mask file that can be applied to other files without going through the full feature detection process. **Mask** will apply the mask settings and **Undo** will allow new settings to be tried. Lastly, Feature Detection can be quit by selecting **Finished** from the displacement image context menu.

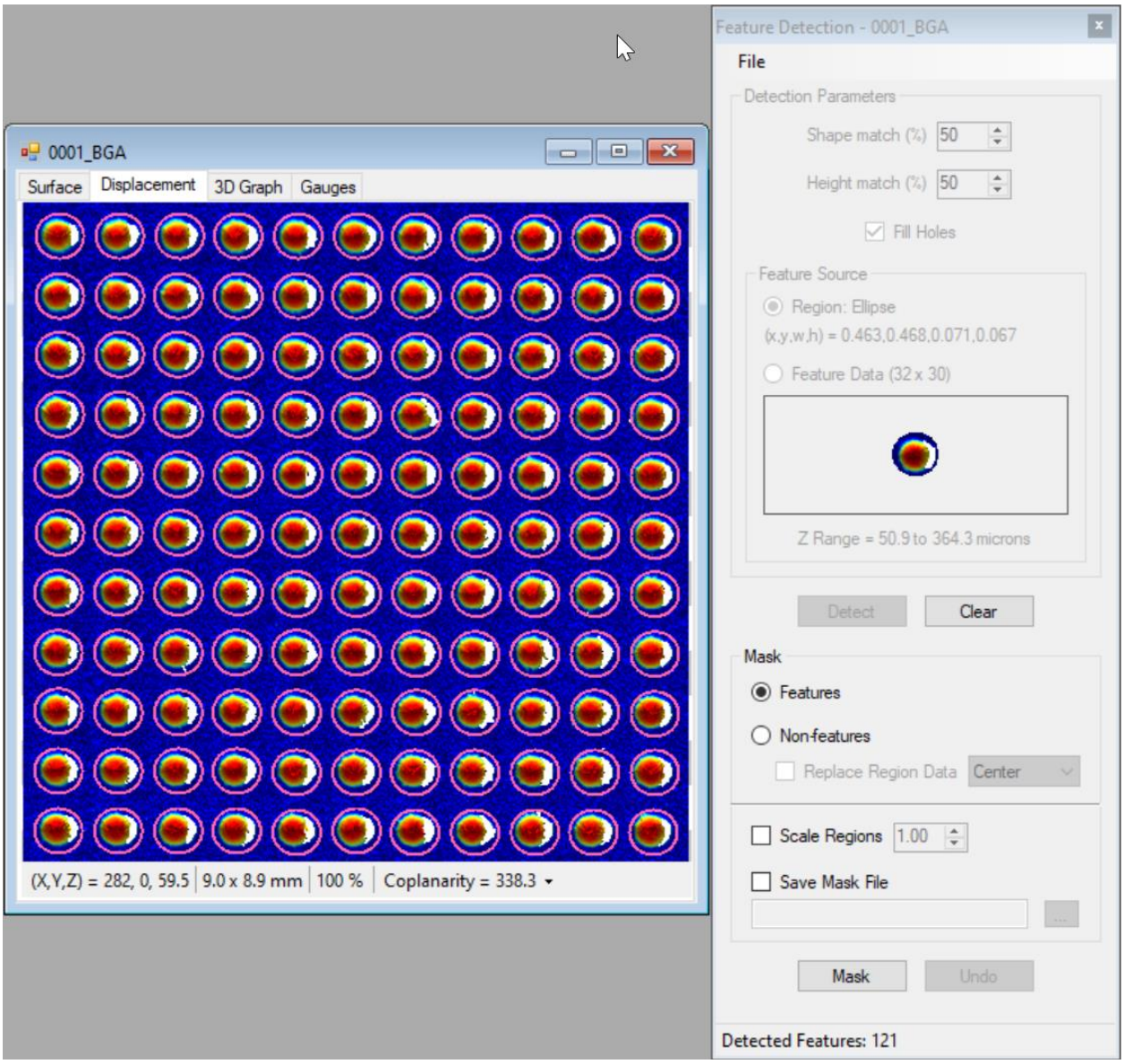


Figure 2.15 Feature Detection with Fill Holes – Solder Ball Peaks on BGA

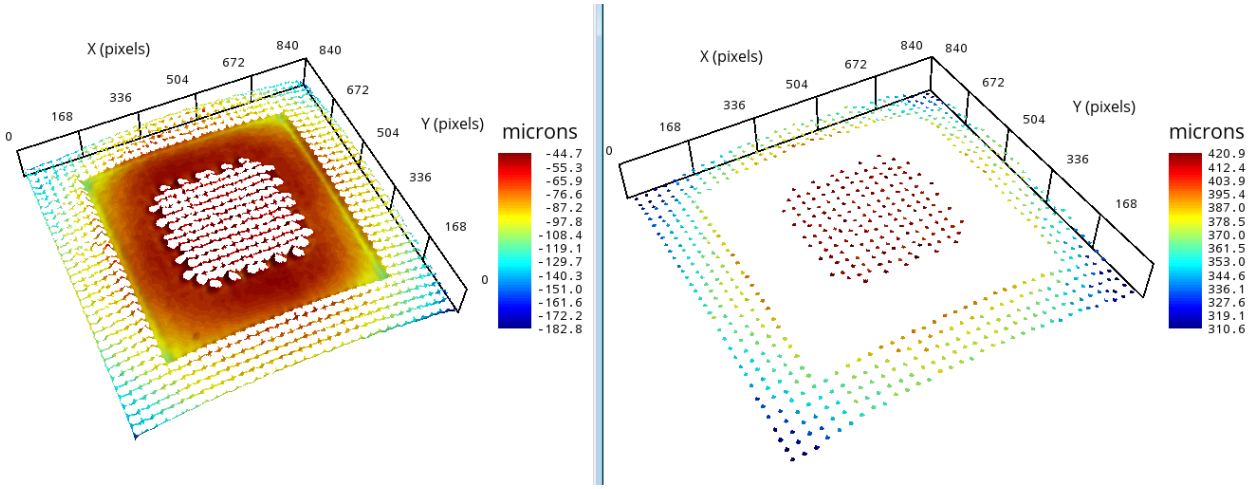


Figure 2.16 Analyzed Data with Feature Detection: Mask Feature and Mask Non-Feature

2.4.8 Z-Range Mask

Z-Range Mask functionality serves as a high and low pass filter for displacement data by filtering based on Z-axis displacement values. Like Feature Detection, this is a modal function that deactivates tab changing. Once Z-Range… is selected from the Mask menu, the Z-range Mask Parameters window will appear (**Figure 2.18**) and the context menu will change to that for Z-Range Mask (Figure 2.17). This mode can be turned off by pressing **Esc** or selecting Cancel from the context menu.

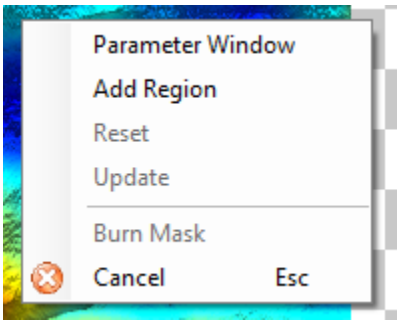


Figure 2.17 Z-Range Mask Context Menu

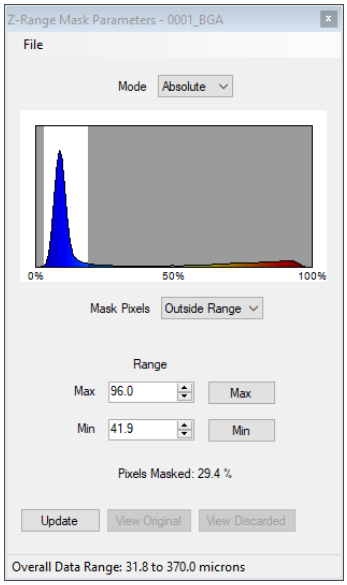


Figure 2.18 Z-Range Mask Parameters Window - Absolute

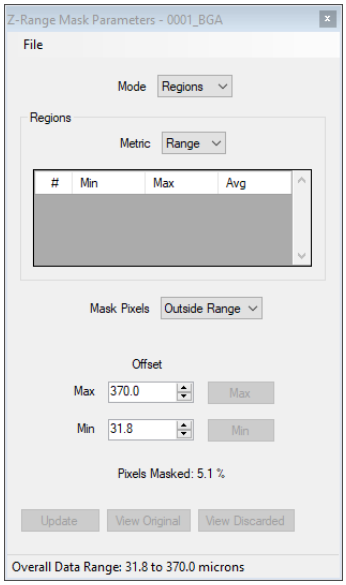


Figure 2.19 Z-Range Mask Parameters Window - Regions

The Z-Range Context Menu has 6 options, listed below.

Parameter Window Opens the Parameter window if it is closed and brings it to the front if it is opened.

Add Region	While Regions mode is active, allows the user to add a region.
Reset	Removes any regions and masks and returns the data to its unfiltered state.
Update	Applies any parameter changes to the data.
Burn Mask	Applies current filtering settings to the displacement image and closes Z-Range Mask Mode.
Cancel	Closes Z-Range Mask mode without applying a mask.

Note: Right-clicking on a single Region brings up a context menu dedicated to ROI editing. Regions are subject to the same ROI editing options described in **Section 3.1**.

The Z-Range Mask Parameters Window File menu has three options. Load allows the current parameters to be saved as a Z-Range Mask File (*.akx_zRangeMask). Save creates a new Z-Range Mask file from the current settings. Finally, Save Map, which activates once a mask has been created, saves a *.akx_mask file from the current Z-Range Mask. This turns the masked data based on Z-Range into a normal, location based mask.

Next, the Z-Range Mode can be chosen between Absolute, Percent, or Regions (**Figure 2.18**). Absolute and Percent modes allow the data to be filtered based on absolute Z-values or as percentages of the total data range. In addition, Absolute or Percent modes show a histogram of the data distribution for easy visualization of where the majority of the data lies. A range can be entered either by left and right clicking on the histogram, or by entering specific Z values in the Min and Max Range fields.

Regions Mode (**Figure 2.19**) allows data to be filtered based on values in selected regions. Once a region has been added via the context menu (**Figure 2.17**) it will be listed in the Regions table, which shows min, max, and average Z values for each added region. The Metric drop-down allows filtering based on the average or range of the regions.

Note: When there are multiple regions, an overall average of all their z values will be used as the result data for Average, and the overall smallest and largest Min and Max values will be used for Range.

The Mask Pixels selection, either Outside Range or Inside Range, chooses how the masked data relates to the range values. Data outside or inside the selected range will be masked out and can be adjusted by changing the Offset values of the maximum or minimum of the data.

Note: In both Regions and Absolute mode, the maximum is the top number and the minimum the bottom.

The bottom of the Z-Range Parameters Window displays data relevant to the masking process and shows results. There is Pixels Masked display which shows the percentage of currently masked pixels and an Overall Data Range of the original image. View Original or View Discarded buttons show what the original data looked like and what portions of it are currently masked out. Finally, the Update button applies the selected Z-Range options to the displacement image. If the result is acceptable, Burn Mask in the context menu (**Figure 2.17**) will make the Z-Range selection permanent and exit the Z-Range mode. Example data filtered by two different Z-Range Masks is shown in **Figure 2.20**.

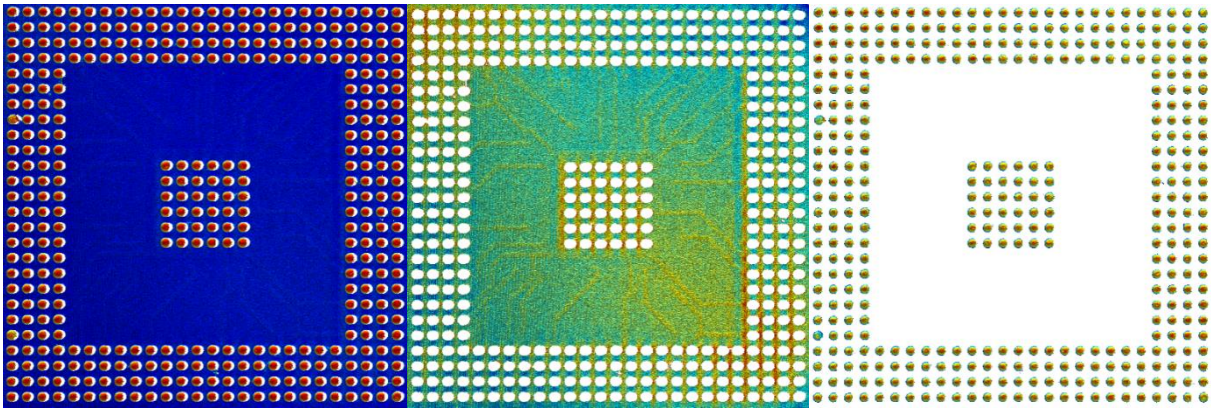


Figure 2.20 Data with High and Low Z-Range Masks

2.4.9 Step Height Calculation

Clicking on **Step Height→Add Step** (**Figure 2.21**) will add a pair of boxes to the displacement view that can be moved around and resized. The step height difference is calculated as the difference in average heights between the two regions (1A-1B). The step height sign will vary depending on whether the A region is higher or lower than B and the result is shown at the bottom of the displacement window (See **Figure 2.22** and **Figure 2.23**). Multiple step height pairs can be added. They can also be saved for loading onto other displacement windows or used as a gauge in batch processing.

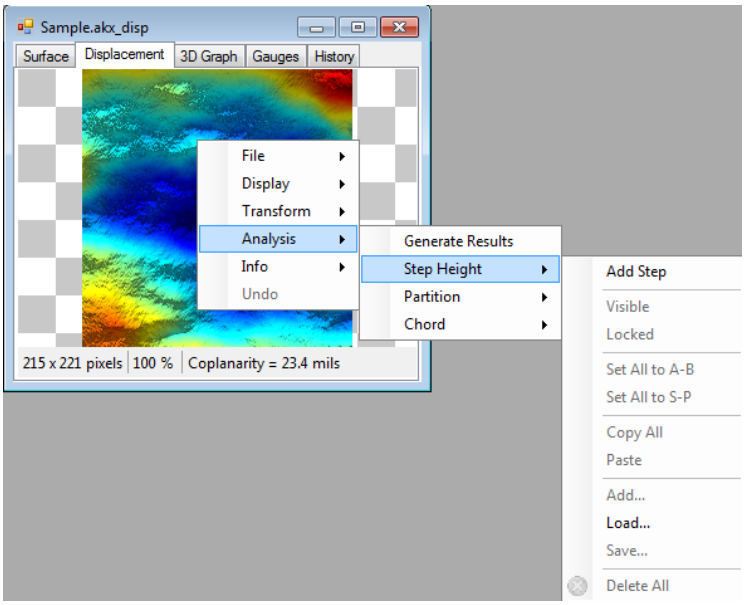


Figure 2.21 Step Height Menu

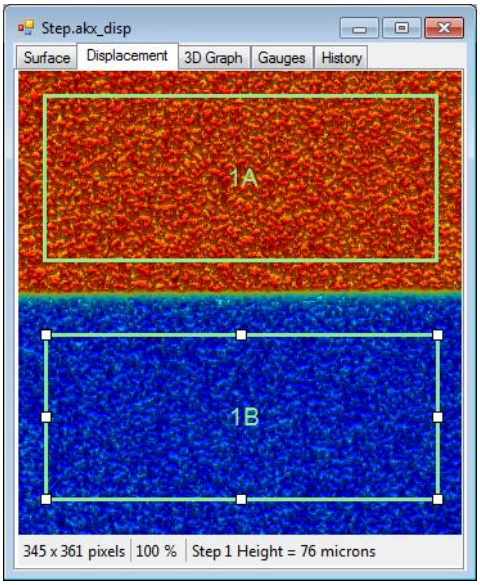


Figure 2.22 Step Height Calculation A>B

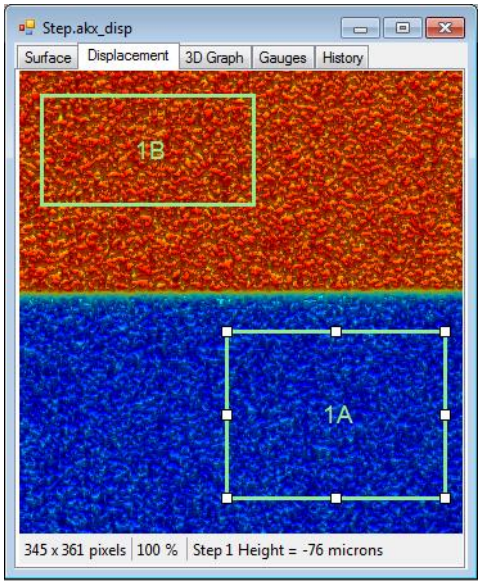


Figure 2.23 Step Height Calculation A<B

The step height pair mode can also be changed by right clicking on either of the boxes and going to **Switch to S-P**. S-P mode uses the 1P box for its LSF reference plane and is most useful when analyzing a calibration block with flat planes and known step heights between them. A-B mode uses the reference plane that is already applied to the surface. See **Figure 2.24** and **Figure 2.25** for an example.

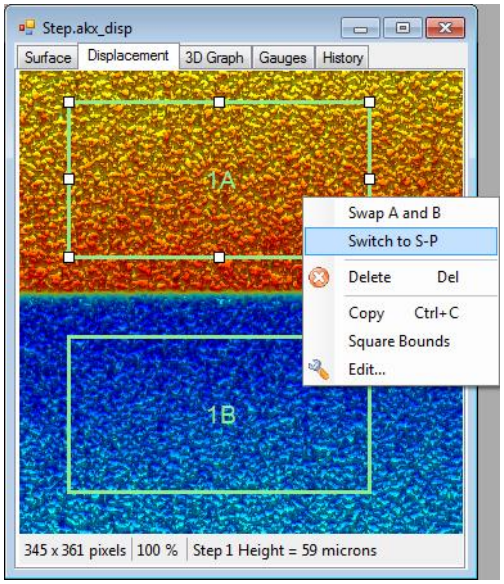


Figure 2.24 A-B Mode

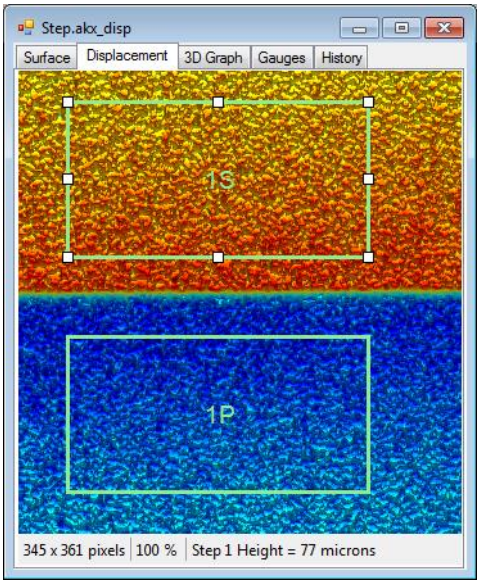


Figure 2.25 S-P Mode

2.4.10 Phase Amplitude Thresholding

As of Studio 8.5, Surface Analysis can now mask displacement images by adjusting the Phase Amplitude Threshold (PAT) of an image and removing low quality data. Both phase and displacement files contain raw intensity data used to build the image, and this is used to determine the quality of the data in various regions. Data is then masked out based on quality.

Unlike PAT for phase files, which is described in **Section 3.4**, data masked via displacement file PAT is unrecoverable after the file has been saved and closed. That data is removed in the same way that data from a burned mask is removed.

In order to adjust the Phase Amplitude Threshold, right click on the displacement image and select **Transform→Mask→Via Phase Amplitude Thresholding…** in the menu. A window will come up with a slider that allows the user to adjust the PAT of the displacement file and see which areas will be masked. Once the user clicks OK and this mask is applied, only the **Undo** function can recover the masked data.

Note: Dragging the slider quickly or large distances may cause some delay in recalculating mask areas. This is particularly true with large displacement images and/or slower computers.

2.5 Saving Displacement Images

A modified displacement image is **NOT** automatically saved to the hard drive. It can be saved using the **File→Save…** menu item. If the modified image is not saved, the user will be prompted again to save it when the displacement image window is closed or the program is shut down.

3 Modifying Measurement Data

Note: Context menu paths described in this section and references to phase images will be different for *.akx_disp files. Behavior of the functions such as masks/partitions/etc. remains the same for displacement images. Reference **Section 2.4**, Working with Displacement Data for correct context menu paths.

3.1 Setting the ROI

The Mask and Partition functions in **Surface Analysis** create one or more graphically defined ROIs (Regions of Interest) on the phase image where these functions can be applied. ROIs can be different shapes such as rectangle, ellipse, triangle, etc. The default shape of an ROI is a rectangle. Choose a new shape by opening the Shape Selector window from the **View→Shape Selector** menu item. Choose the shape before selecting the Mask or Partition function (**Figure 3.1**).

After activating the desired function (Mask or Partition), click and drag the mouse cursor from one corner of the desired ROI to the other. When an ROI region is selected, it can be repositioned by dragging anywhere within its region and resized by dragging on any of the eight “Handles” on the periphery. The shape, location, and size of the ROI can also be changed by using the ROI Edit Window (**Figure 3.2**). To access this window, right-click inside the ROI and choose **Edit…**. This window is useful for drawing a pre-defined ROI. Size can be defined in either absolute (pixel) terms or fractional terms (relative to the phase image dimensions). In the case of Partition regions, Chords, and Step Heights, name of the ROI can also be edited.

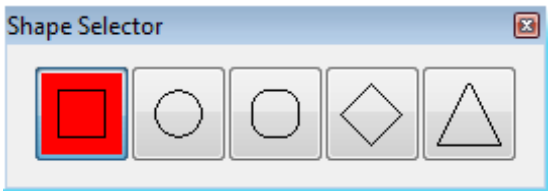


Figure 3.1 ROI Shape Selector

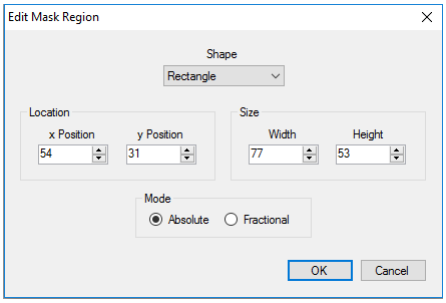


Figure 3.2 Edit ROI Region Size and Position

Other common functions for Masking and Partitioning can be called by right-clicking inside an ROI:

Copy (**Ctrl+C**) creates a copy of the active ROI on the Windows Clipboard. It may be pasted (**Ctrl+V**) inside the original phase image or in a different phase image.

Square Bounds equalizes the horizontal and vertical dimensions of the ROI as the shorter value of the two

Delete deletes the active ROI(s)

Delete All deletes all ROIs within the current phase image window

Note: Other functions in Surface Analysis, such as Feature Detection and Z-Range Mask, also use ROIs in their interfaces. These ROIs can be edited using the functionality described above.

Note: Multiple ROIs, whether Mask, Partition, etc., can be selected by using Ctrl+Click. This allows the user to interact with multiple ROIs at once.

3.2 Masking a Phase Image

Masking excludes regions inside the phase image from the analysis. Regions that lack good phase data (e.g. holes, steps) can create errors in the analysis that extend beyond the bad phase region. When using a mask, there is no displacement information generated within the masked-out regions, and the remainder of the phase image can be analyzed without interference.

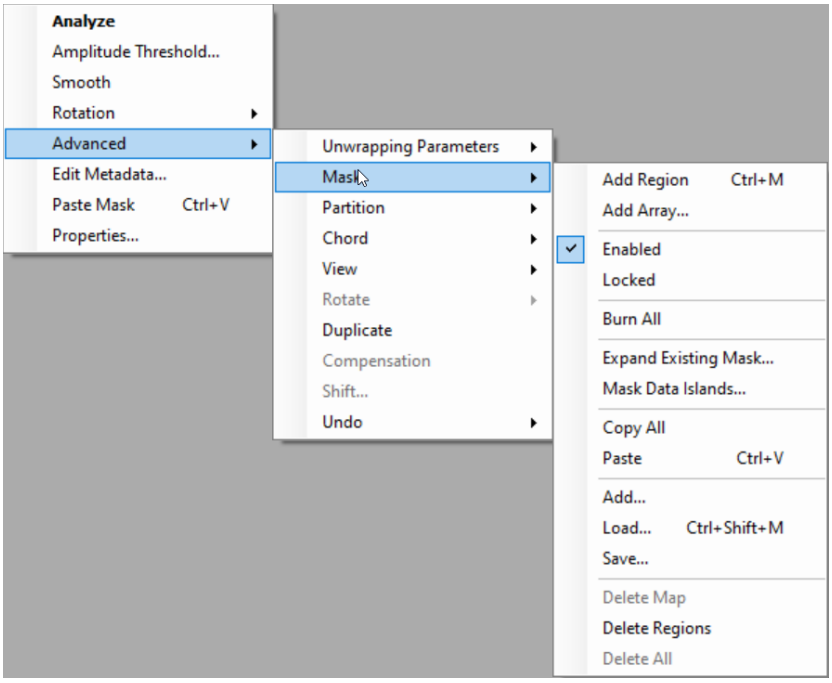


Figure 3.3 Mask Menu

3.2.1 Creating a Mask

A mask file can be either a binary graphical image (*.png) containing only black and white colors or a *.akx_mask file representing the location, shape, and size of the regions added during a mask operation. In the case of an image mask, the white color represents valid data while the black color represents points or areas that need to be masked out. In most cases, the mask shapes shown in **Figure 3.1** are sufficient. However, if the user needs to define an irregularly shaped mask, they can also be generated from an external graphical tool such as *MS Paint*®. The file format needs to be *.bmp or *.png in order to be loaded in **Surface Analysis**.

A mask can be created and saved in **Surface Analysis** by the following steps:

1. To create a new mask, right-click in the selected phase image and choose **Advanced→Mask→Add Region** (or use the keyboard shortcut, **Ctrl+M**).
2. To create the first ROI in the new mask, hold down the left mouse button; draw a rectangle on the phase image and then release. The ROI will appear as a transparent red shape. All the ROI commands described in **Section 3.1** apply to the mask ROI.
3. Additional mask ROIs can be added by repeating steps 1 and 2. Mask ROIs may overlap.
4. When the mask is complete, it may be saved to a file (*.akx_mask or *.png) by right-clicking inside the phase image (but not inside an editable mask ROI) and choosing **Advanced→Mask→Save…**.
5. The mask can be turned on and off without deleting the mask from memory by right-clicking inside the phase image (but not inside an editable mask ROI) and choosing **Advanced→Mask→Enabled**. Alternating this command will turn the current mask(s) on and off. This is useful when evaluating masks between phase image and 3D surface plot during analysis. When the masking function is disabled, all mask ROIs are hidden.
6. The mask can be locked by going to **Advanced→Mask→Locked**. This setting will prevent the user from interacting with any editable (red transparent) mask regions. It is selected by default when adding a Mask Array (see **Section 3.2.5**).

3.2.2 Loading and Editing a Mask

A previously created mask that was saved in the *.akx_mask, or *.png, formats can be recalled and applied to any phase image. To load the mask file, right-click inside the phase image, choose **Advanced→Mask→Load…** (or use the keyboard shortcut, **Ctrl+Shift+M**), and select the desired mask file. More than one mask file can be loaded on the same phase image. An image mask is shown in solid yellow color while a *.akx_mask file is shown as an editable transparent red region.

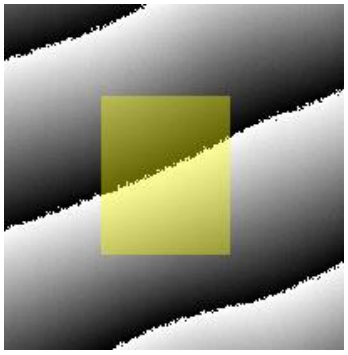


Figure 3.4 Loaded Image Mask in Yellow

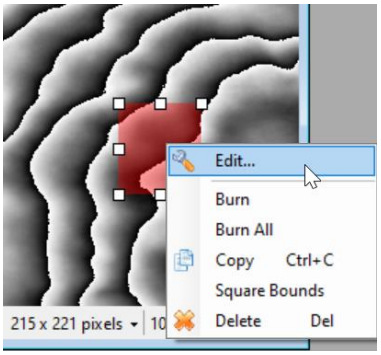


Figure 3.5 Loaded Annotation Mask in Red

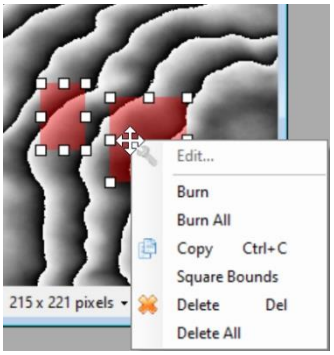


Figure 3.6 Multiple Annotation Masks Selected using Ctrl modifier key

A loaded image mask cannot be edited but can be turned on and off by toggling the **Advanced→Mask→Enable** function. To delete a loaded image mask, choose **Advanced→Mask→Delete Map**. To delete a loaded *.akx_mask mask, choose

Advanced→Mask→Delete Regions, or right click on the red region and a context menu, including **Delete**, appears (**Figure 3.5**). Multiple regions can be selected and interacted with by holding down the **Ctrl** key while clicking on regions (**Figure 3.6**). New mask ROIs may be added by right-clicking inside the phase image and choosing **Advanced→Mask→Add Region**.

The modified mask, including both old and new components, can be saved by right-clicking inside the phase image (but not inside an editable mask ROI) and choosing **Advanced→Mask→Save…**.

Note: If a mask is loaded onto a phase image with different pixel dimensions than the one on which it was created, a dialog will appear, as shown in either **Figure 3.7** or **Figure 3.8**.

In **Figure 3.7**, when loading a mismatched Annotation mask, Scale layout will use the fractional values from the mask relative to the original phase image dimensions. Preserve layout will load the regions using the raw pixel dimensions and coordinates.

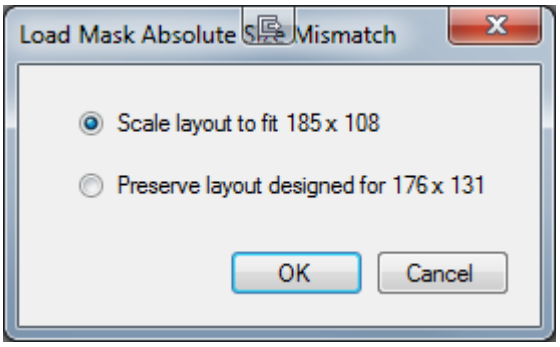


Figure 3.7 Load Annotation Mask Mismatched Size Dialog

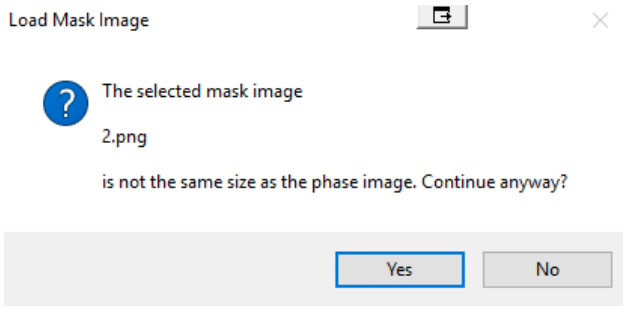


Figure 3.8 Load Image Mask Mismatched Size Dialog

In **Figure 3.8**, when loading a mismatched Image mask, clicking Yes on the dialog will load the image mask regardless of the mismatch, scaling the masked regions to the aspect ratio of the current phase image.

3.2.3 Copying and Pasting Masks

All masks on a phase image can be copied by going to **Advanced→Mask→Copy All**. Alternatively, individual mask regions can be copied and pasted by right clicking on them and going to **Copy**. When a region is selected the shortcut **Ctrl+C** also works.

Pasting a mask is similar. Once a mask region has been copied, right click on the target phase image and go to **Paste Mask**. When the target phase image has focus, the shortcut **Ctrl+V** also works for this function.

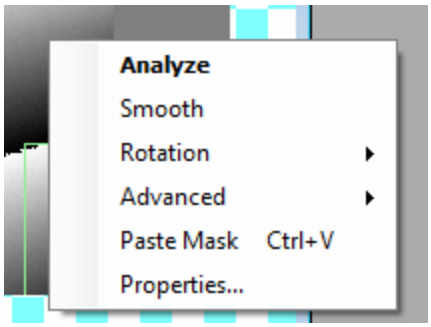


Figure 3.9 Paste Mask Option in Phase Image Context Menu

Note: If a mask is pasted onto a phase image with different pixel dimensions than the one on which it was created, the mask will be scaled fractionally in location and size.

3.2.4 Burning a Mask

Burning a mask combines the current phase image with one or more mask ROIs created in memory or loaded from a file. The mask pattern will be permanently embedded in the phase image. This function prevents the future separation and loss of mask files used during analysis.

A mask can be burned by:

- right-clicking inside an editable mask ROI and choosing **Burn**
- right-clicking inside the phase image (but not inside an editable mask ROI) and choosing **Advanced→Mask→Burn All**.

The burned mask ROIs appear in gray as shown in **Figure 3.10**.

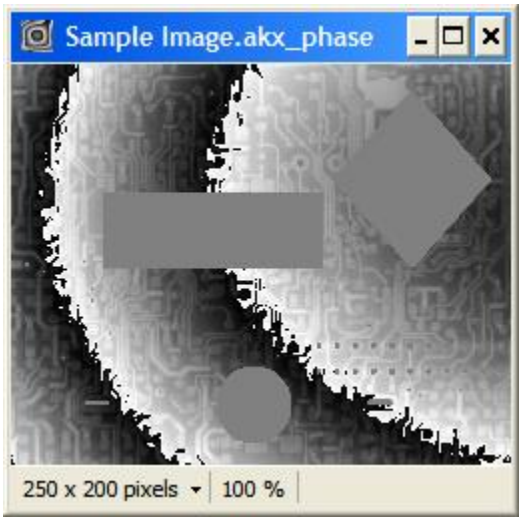


Figure 3.10 Burned Mask Areas

3.2.5 Adding a Mask Array

Instead of adding mask ROIs one by one, an array of mask ROIs (**Figure 3.11**) can be created using the Mask Array tool. This function is useful for automatically creating repetitive mask regions on a phase image.

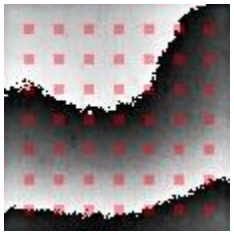


Figure 3.11 Example of a Mask Array

1. To create a new array right click in the selected phase image and choose **Advanced→Mask→Add Array…**
2. A checkerboard pattern representing where mask regions will be placed appears on the phase image. Also, a window with various array parameter options appears (**Figure 3.12**). **Width** and **Height** refer to the individual dimensions of each mask region. **Pattern Origin** is the distance of the center of the pattern from the center of the image. **Spacing** controls how much space exists between each mask region. **Region Inset** refers to how much of each pattern region is covered by the final mask (a larger inset reduces the size of each mask region). Finally, **Selection Area** controls whether the mask array is placed inside or outside the green bounding box. Each option affects all ROIs in the same way.

Note: There is no way to edit one mask region at this stage. Once the mask array has been added, the shape and location of each region can be altered individually.

3. Click the **Update** button to view changes made to the pattern on the phase image.

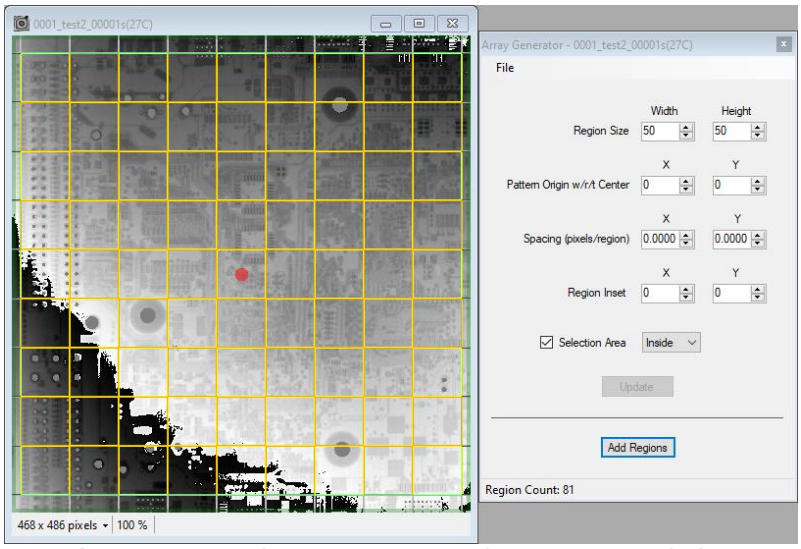


Figure 3.12 Mask Array Pattern and Parameters Window

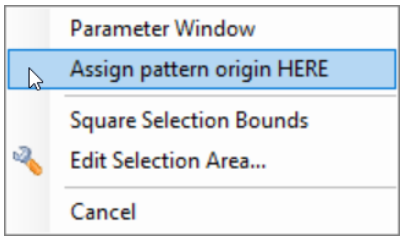


Figure 3.13 Array Context Menu

4. The array pattern origin can be changed graphically by right clicking at the desired point on the phase image and selecting **Assign pattern origin HERE** (**Figure 3.13**).
5. To save the mask regions, use the green array bounding box to select the specific regions to be saved. The bounding box can be edited via the Array Context Menu to square its dimensions or edit its position and size (**Figure 3.13**). Note that only regions whose whole areas are enclosed by the green bounding box will be saved, as seen in **Figure 3.14** and **Figure 3.15**. Click on **Add Regions** to add the selected regions. The program will lock these regions so that they cannot be edited. Interaction with the created array can occur just as with a normal mask (see **Section 3.2.1**).

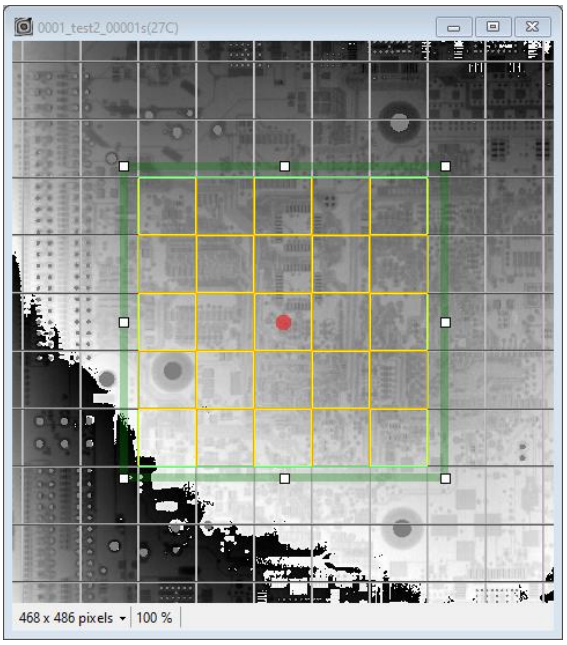


Figure 3.14 Mask Array Green Bounding Box

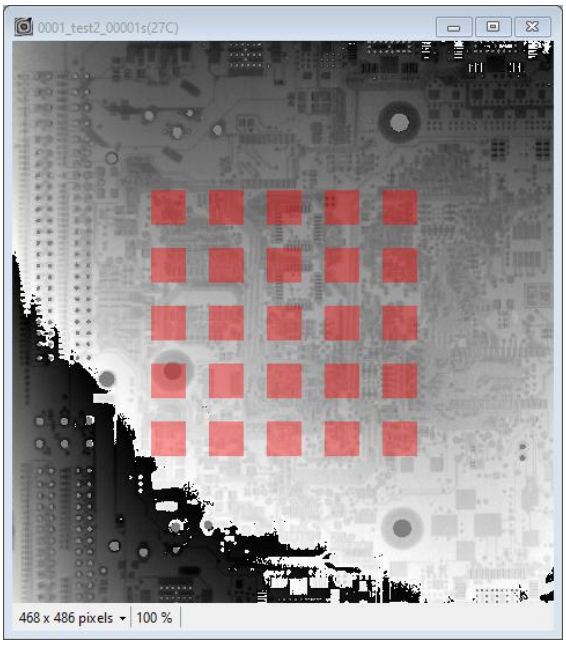


Figure 3.15 Added Mask Array

3.2.6 Expand Existing Mask

As of Studio 8.5, the Expand Existing Mask feature gives the user the ability to extend burned mask regions. This is useful for eliminating bad data not quite covered by the original mask without having to draw new masks. It's also useful for expanding linearly on areas that were initially covered by Phase Amplitude Thresholding.

To expand all burned masks in an image, right click in the selected phase or displacement image and choose **Advanced→Mask→Expand Existing Mask…**

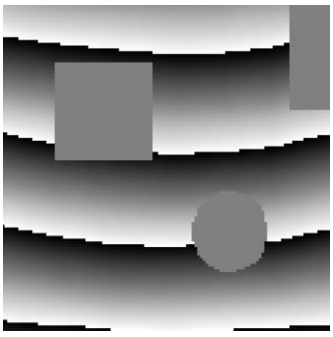


Figure 3.16 Before Expanding Existing Mask

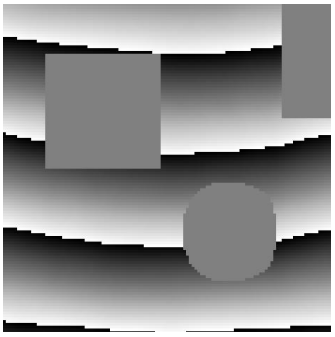


Figure 3.17 After Expanding Existing Mask

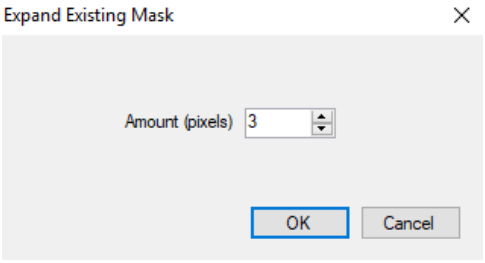


Figure 3.18 Expand Existing Mask

3.2.7 Mask Data Islands

As of Studio 8.5, the Mask Data Islands function gives the user the ability to mask islands in the data based on their pixel size, removing regions smaller than a given threshold. This is most useful when working with *.akx_disp files, since unwrapping for phase images works on contiguous areas and ignores disconnected islands (see **Section 4.6**). For *.akx_disp images, however, the ability to remove small islands of data as a group instead of manually can be very effective for noise reduction or selecting the correct area for measurement.

To mask data islands, right click on the selected image and select **Advanced→Mask→Mask Data Islands…**. The user then enters a pixel size of the largest island to be masked.

3.3 Cropping a Phase Image

Cropping an image allows the user to extract and save a smaller portion of the current phase image. This is useful for defining a smaller region inside the original phase image or eliminating bad phase data at an image edge.

Note: As of Studio 8.0, the crop function has been removed in favor of creating a partition file with only one region. Please see **Section 3.5**.

3.4 Phase Amplitude Thresholding

As of Studio 8.0, Surface Analysis now has the ability to adjust the phase amplitude threshold used to auto-mask a phase image after it has been saved by Surface Measurement. Previously, this value could only be changed by re-acquiring data during acquisition. This works by virtue of the fact that *.akx_phase files typically store the raw

intensity images used to build phase data. By resetting the phase amplitude value, areas of the image that were above the acquisition PAT can be recovered and data that should have been masked can be removed.

In order to adjust the Phase Amplitude Threshold, right click on the phase image and select the **Amplitude Threshold…** menu option. A dialog will pop up asking the user whether or not they want to keep existing masked points. Clicking Yes will create a map of the already masked out points that will not be affected by any PAT adjustments. This is particularly useful if the user has already created a mask of data that had good phase amplitude but was simply not needed in the measurement. Saying No will recalculate mask on all areas of the image.

As of Studio 8.5, displacement images can also be Phase Amplitude masked, but displacement data can only be removed, not recovered. See **Section 2.4.10**.

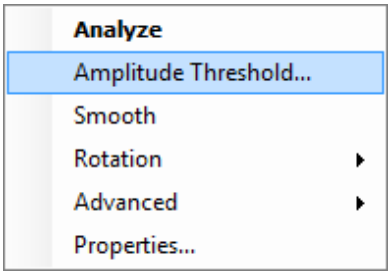


Figure 3.19 Amplitude Threshold Menu Option

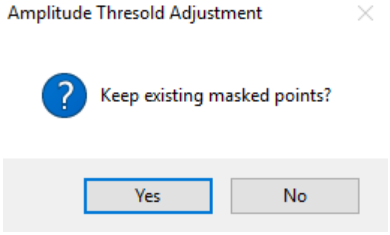


Figure 3.20 PAT Keep Existing Masked Points?

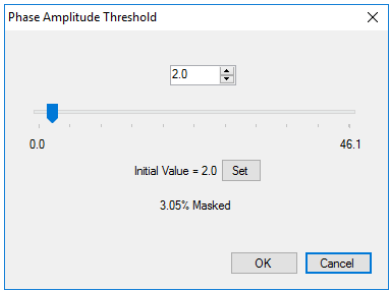


Figure 3.21 Phase Amplitude Thresholding Adjustment Window

When the adjustment window pops up, move the slider to adjust mask calculation. The Min and Max values on this slider are pulled directly from the phase amplitude of the image.

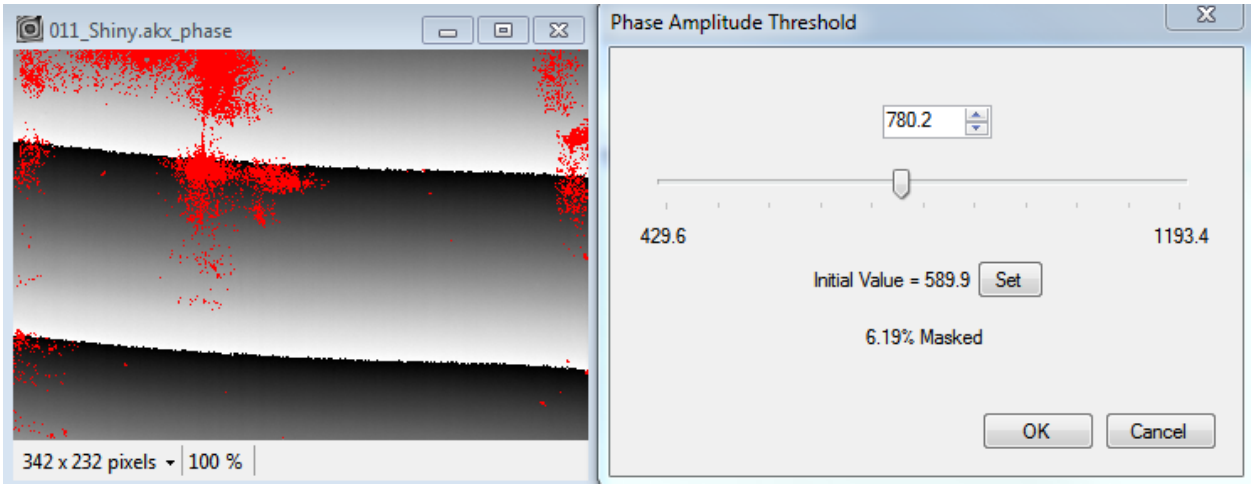


Figure 3.22 Phase Amplitude Thresholding

Masked areas will increase and decrease, and be highlighted red on the phase image. To go back to the original PAT value, click the Set button.

Note: Dragging the slider quickly or large distances may cause some delay in recalculating mask areas. This is particularly true with large phase images and/or slower computers.

In Batch Processing, the Phase Amplitude Threshold dialog has both absolute and relative threshold settings, as well as both 8-bit and 12-bit scales, depending on which type of image is being processed.

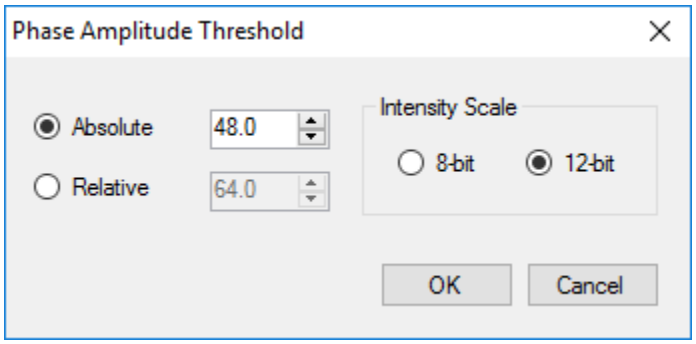


Figure 3.23 Phase Amplitude Threshold Batch Dialog

3.5 Partitioning a Phase Image

Partitioning is a function where one or more ROIs are cropped from a phase image while leaving the original phase image intact. This function is useful for measuring multiple samples in a single run, and later extracting the individual samples from each phase image recorded. The same partition can be applied to multiple phase images using the Batch Cropping tool described in **Section 7**.

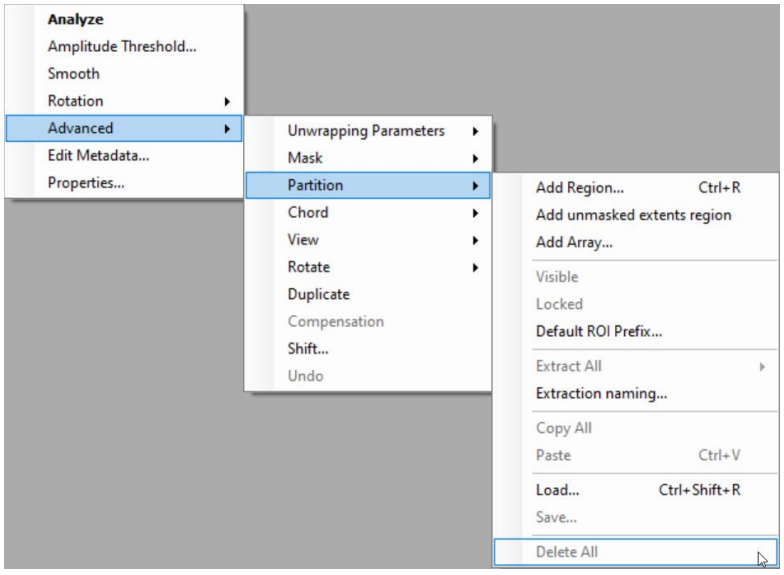


Figure 3.24 Partition Menu

3.5.1 Creating a Partition

1. To create a new partition, right-click in the selected phase image and choose **Advanced→Partition→Add Region…** (or **Ctrl+R**).

2. To create the first domain in the new partition, draw a rectangle on the phase image with the mouse.
3. A green ROI appears and all the ROI commands described in **Section 3.1** apply to the partition ROI. By default, the regions will be named “Region 001”, “Region 002”, etc, but the default can be changed by going to **Advanced→Partition→Default ROI Prefix…** Previously used ROI names will be saved in a list for recall later.

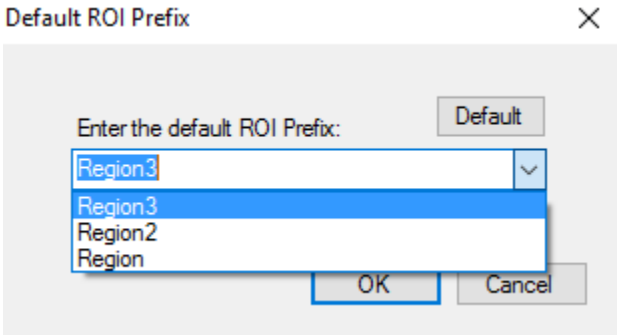


Figure 3.25 Default ROI Prefix Dialog

4. Right-clicking inside any ROI and choosing **Edit…** allows the region name to be changed as well as the shape, location, size, and Mode of the domain (**Figure 3.26**). Click **OK** when complete.

Note: The Mode selection determines whether the partition location and size are displayed in absolute pixels or fractions. The location is relative to the top left corner of the phase image. The size is relative to the full x and y dimension of the phase image.

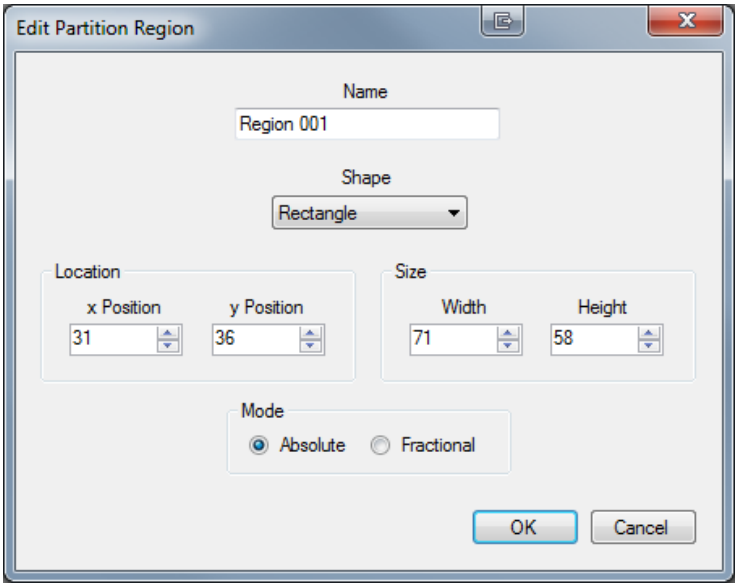


Figure 3.26 A Partition ROI Properties Window

5. Additional domains can be added to the partition (**Figure 3.27**) by repeating steps 1 through 3. Domains may overlap.

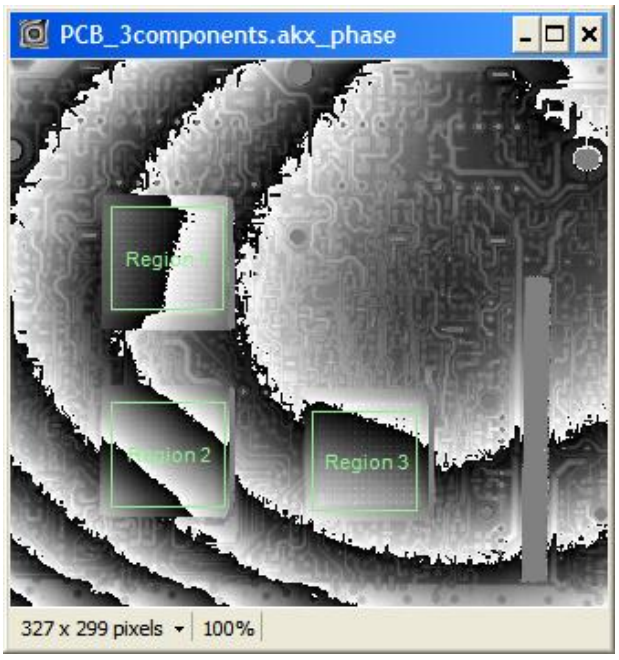


Figure 3.27 Multiple Domains on One Phase Image

6. When the partition is complete, it can be saved to a file (*.akx_partition) by right-clicking inside the phase image (but not inside a domain) and choosing **Advanced→Partition→Save…**.
7. Even if it has not been saved, a partition may be used until it is cleared. It may be cleared by right-clicking inside the phase image (but not inside a domain) and choosing **Advanced→Partition→Delete All**.
8. The partition can be locked by going to **Advanced→Partition→Locked**. This setting will prevent the user from interacting with any editable partition regions. It is selected by default when adding a Partition Array (see **Section 3.5.5**).
9. The partition can be made visible or invisible by going to **Advanced→Partition→Visible**.

3.5.2 Loading and Editing a Partition

A previously created partition that was saved in a *.akx_partition file can be recalled and applied to any phase image. To load the partition file, right-click inside the phase image, choose **Advanced→Partition→Load…** (or use the keyboard shortcut, **Ctrl+Shift+M**), and select the desired partition file.

Any domain in the partition may be modified or deleted by right-clicking inside the domain and using the ROI commands described in **Section 3.1**. It may also be edited graphically using the cursor. New domains may be added by right-clicking inside the phase image (but not inside a domain) and choosing **Advanced→Partition→Add Region…**.

The modified partition, including both old and new domains, may be saved by right-clicking inside the phase image (but not inside a domain) and choosing **Advanced→Partition→Save…**.

Note: If a partition is loaded onto a phase image with different pixel dimensions than the one on which it was created, a dialog will appear, as shown and discussed below.

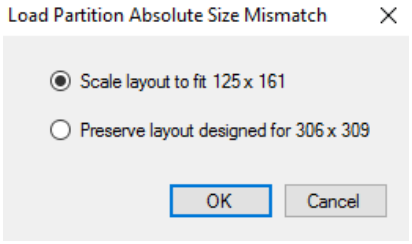


Figure 3.28 Load Partition Absolute Size Mismatch

Scale layout will use the fractional values from the mask relative to the original phase image dimensions. Preserve layout will load the regions using the raw pixel dimensions and coordinates. If Preserve is chosen, a dialog will let the user know how many regions were discarded because they were entirely outside of the data bounds as well as how many regions extend outside of the data bounds. Only regions with their top left corner present in the target image pixel bounds will be loaded.

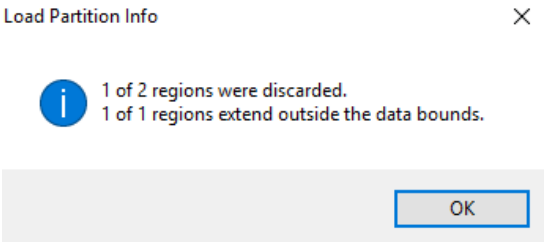


Figure 3.29 Load Partition Preserve Layout Info

3.5.3 Copying and Pasting Partition Regions

A mask can be copied by going to **Advanced→Partition→Copy All**. Alternatively, individual partition regions can be copied and pasted by right clicking on them and going to **Copy**. When a region is selected the shortcut **Ctrl+C** also works here.

Pasting a partition is similar. Once a partition region has been copied, right click on the target phase image, and go to **Paste Partition Region**. When the target phase image has focus, the shortcut **Ctrl+V** also works for this function.

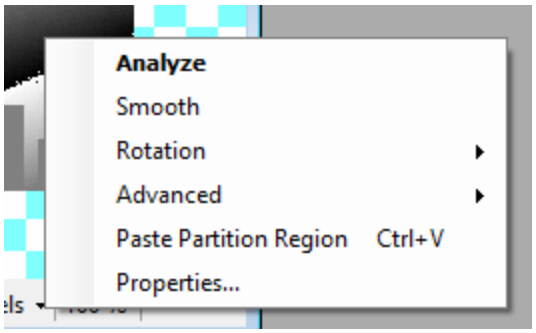


Figure 3.30 Paste Partition Region Option in Phase Image Context Menu

Note: If a partition is pasted onto a phase image with different pixel dimensions than the one on which it was created, the region will be scaled fractionally in location and size.

3.5.4 Extracting Domains

Partitions can be extracted from the original phase image, either to new windows (**Figure 3.31**) or to independent *.akx_phase files. To extract a domain as an independent phase image in its own window, right-click inside the domain and choose **Extract**, then choose between '**to window'** and **'to file…'** (**Figure 3.32**). To extract all domains when multiple exist, right-click inside any ROI and choose **Extract All**, and again choose to extract to windows or files. If **'to windows'** is chosen, a new window will pop up for each ROI.

When partitions are extracted to files, the default file name is the ROI name appended to the name of the parent file (Example: Sample_0001.akx_phase). This default can be changed in **Advanced→Partition→Extraction Naming**. The default file names can be edited when extracting individual partitions to files, but are used automatically when **Extract All→'to files…'** is chosen.

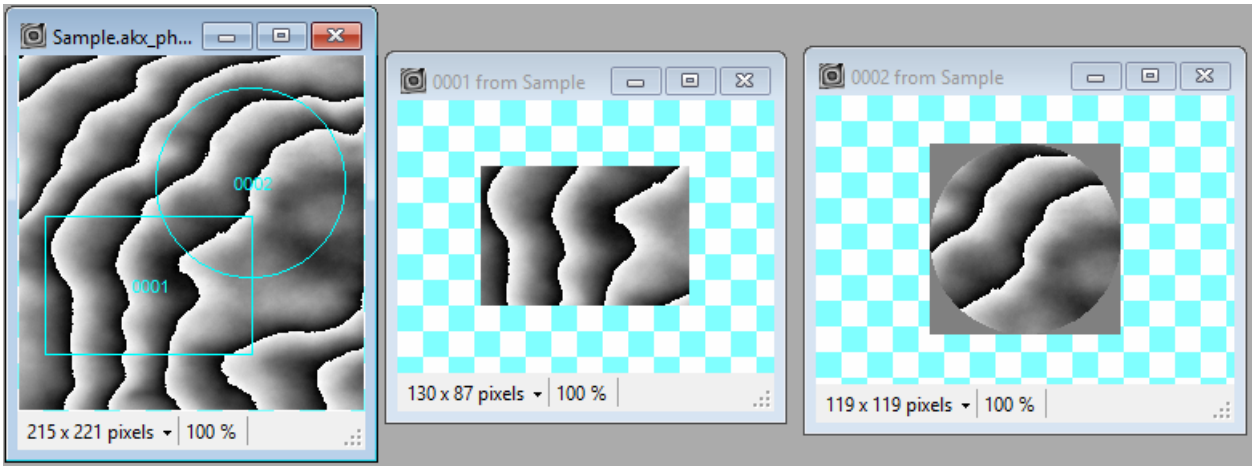


Figure 3.31 Extracted Domains from a Phase Image

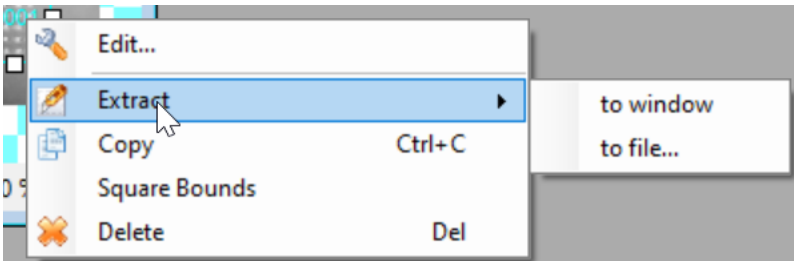


Figure 3.32 Partition Context Menu - Extract

3.5.5 Adding a Partition Array

Instead of adding partition ROIs one by one, an array of partition ROIs (**Figure 3.33**) can be created using the Partition Array tool. This function is useful for automatically creating repetitive partition regions on a phase image. Common use cases include examining die level warpage on wafers and package level warpage on strips.

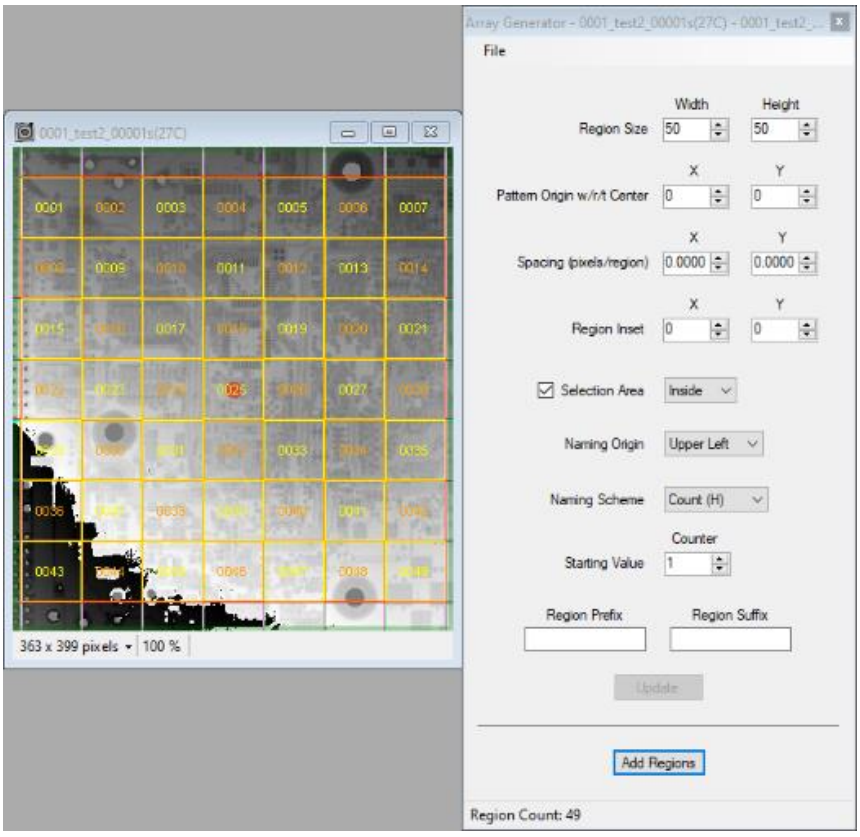
Figure 3.33 Example of a Partition Array

1. To create a new array right click in the selected phase image and choose **Advanced→Partition→Add Array…**
2. A checkerboard pattern representing where partition regions will be placed appears on the phase image. Also, a window with various array parameter options appears (**Figure 3.34**). **Width** and **Height** refer to the individual dimensions of each partition region. The **Pattern Origin** is the distance of the center of the pattern from the center of the image. **Spacing** controls how much space exists between each partition region. **Region Inset** refers to how much of each pattern region is covered by the final partition (a larger inset reduces the size of each partition region). Finally, **Selection Area** controls whether the partition array is placed inside or outside the green bounding box. Each option affects all ROIs in the same way.

Note: There is no way to edit one partition region at this stage. Once the partition array has been added, the shape, location, and name of each region can be altered individually.

3. Partitions will be numbered by default and **Naming Origin** determines where the first partition originates. The **Naming Scheme** parameter allows for sequential or row-column style naming of the partitions. The **Starting Value** option allows the numbering to begin at arbitrary values. Finally, the numbering scheme can have a **Prefix** or **Suffix** added for additional naming flexibility.

4. Click **Update** to view the changed array inside the phase image.
5. The array pattern origin can be changed graphically by right clicking at the desired point on the phase image and selecting **Assign pattern origin HERE** (**Figure 3.35**).



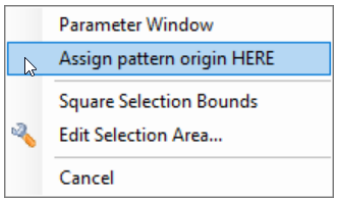


Figure 3.35 Array Context Menu

Figure 3.34 Partition Array Parameters

6. To save the partition regions, use the green array bounding box to select the specific regions to be saved. The bounding box can be edited via the Array Context Menu to square its dimensions or edit its position and size (**Figure 3.35**). Note that only regions whose whole areas are enclosed by the green bounding box will be saved, as seen in **Figure 3.36** and **Figure 3.37**. Click on **Add Regions** to add the selected regions. The program will lock these regions so that they cannot be edited. Interaction with the created array can occur just as with a normal partition (see **Section 3.5.1**).

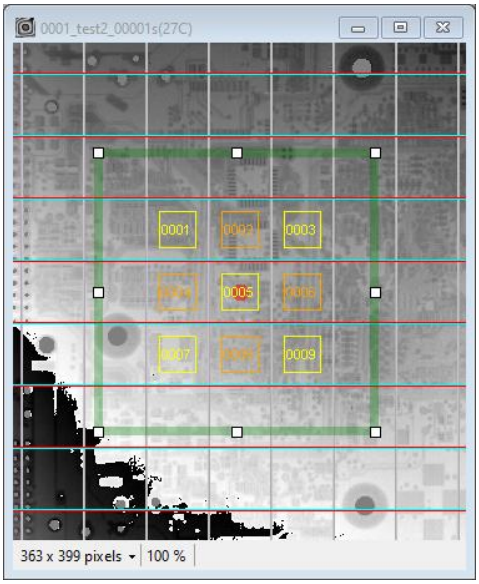


Figure 3.36 Green Array Bounding Box

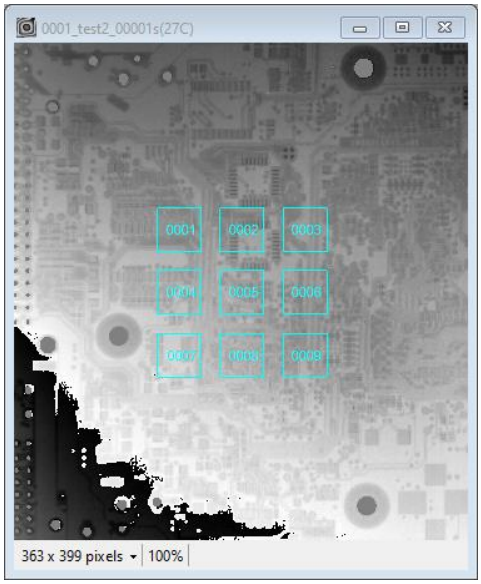


Figure 3.37 Added Partition Array

3.5.6 Add Unmasked Extents Region

The Add Unmasked Extents Region function creates a region that encompasses the furthest unmasked edges of an image, allowing the user to quickly extract images with unmasked data up to the edges. This is most useful for obtaining normalized and edge chords from images that required edge masking to cover bad data. **Figure 3.38** shows an example image with an unmasked extents region already created.

To create an unmasked extents region, right-click in the selected image and choose **Advanced→Partition→Add Unmasked extents region**.

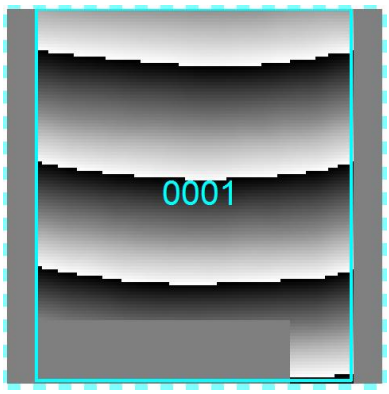


Figure 3.38 Unmasked Extents Region

3.6 Smoothing a Phase Image

The **Smooth** command applies a smoothing function to the active phase image to reduce noise in the data. This is useful for reducing analysis error due to fringe miscounting and increasing reproducibility in gauge values. Warpage gauge values, such as coplanarity, are frequently determined by a small number of data points, e.g. the highest and lowest displacement values. Therefore, they are extremely sensitive to

statistical outliers in the data set. Smoothing, by reducing statistical noise, can make these values more repeatable from measurement to measurement.

To apply the smooth function, right-click inside the phase image and choose **Smooth**. This command can be repeated multiple times. For further information about the smooth function, refer to **Akrometrix Optical Techniques and Analysis 101**.

Note: Smoothing may cause errors when applied to images where the fringes are very tightly spaced or at boundaries of mask ROIs. Therefore, it is not recommended to apply the smooth function on data acquired with the **MP10 Surface Measurement** system which produces a closely spaced fringe pattern on a phase image.

3.7 Rotating a Phase Image

Rotating a phase image is a feature useful when a sample does not have the desired orientation in the original phase image (e.g. a part has rotated on the sample support fixture during a temperature profile).

Note: Phase image rotation is different from reference plane rotation that is discussed in **Section 4.3**. The former rotates a 2D image while the latter rotates a 3D surface. To choose the method of rotating a reference plane, right-click on the phase image and choose **Rotation** (**Figure 3.40**).

To rotate a phase image, right-click on the image, choose **Advanced→Rotate** and select the desired rotation.

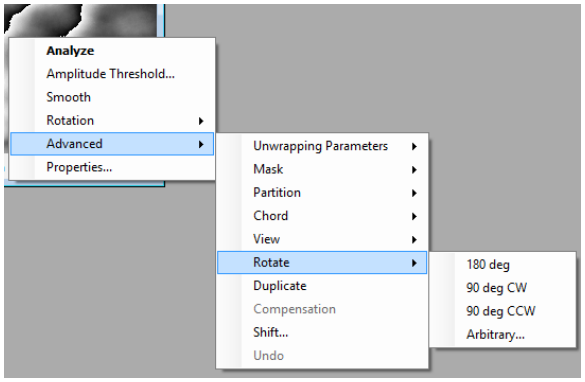


Figure 3.39 Phase Image Rotation

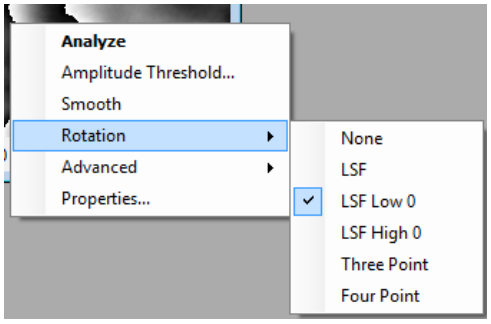


Figure 3.40 Reference Plane Rotation

3.8 Shifting a Phase Image

Shifting a phase image is a feature useful when a sample does not have the desired position in the original phase image (e.g. a part has shifted to one side of the sample support fixture during a temperature profile).

To shift a phase image, right-click on the phase image, choose **Advanced→Shift…** and select the desired shift in either the X (left-right) or Y (up-down) direction. The image

will shift with respect to an origin that is defined as the top left of the phase image. Areas shifted from outside the boundaries of the phase image will be filled with mask (see **Figure 3.41**).

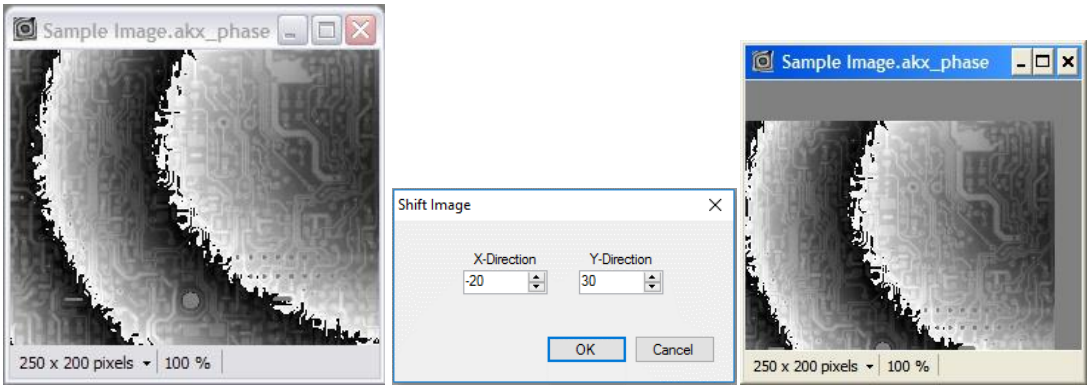


Figure 3.41 Shifting a Phase Image

3.9 Undoing a Phase Image Modification

To undo phase image modification from masking, partitioning, smoothing, rotating or shifting, right-click and select **Advanced→Undo**; select the action to undo from the available list.

There can be up to 99 actions on the undo list. The latest action will be shown at the top of the list. Clicking on the latest action will remove this single action and move the phase image back one state. Clicking on any item in the middle of the list will remove all the actions from the top to this item.

3.10 Saving Phase Images

A modified phase image is **NOT** automatically saved to the hard drive. It can be saved using the **File→Save…** menu item. If the modified image is not saved, the user will be prompted again to save it when the phase image window is closed or the program is shut down.

4 Analyzing Measurement Data

Analysis is the mathematical conversion of the measurement data (e.g. phase image) into displacement data (the height of the surface at each image pixel in physical units). **Surface Analysis** is normally set to display displacement data graphically as soon as the analysis is complete. The graphical *output* options will be described in **Section 4.6**. This section describes how to initiate the analysis process and a key factor in the analysis, the choice of reference plane.

4.1 Analysis

There are three methods to trigger analysis of the measurement data

A. To trigger analysis manually, right-click on the phase or displacement image to be analyzed and select **Analyze**.

B. To trigger analysis automatically when a *.akx_phase file is opened, select the **Tools→Options…** menu item and check **Analyze on Open**.

C. To analyze multiple measurement data in parallel, use the **Batch Analysis** function described in **Section 7.2**.

Note: If no graphical display options are checked in the options window, there will be no visible indication that analysis has taken place in cases A and B above.

4.2 The Options Window

The settings on the options window (**Figure 4.1**) determine the reference plane and display options when the measurement data is analyzed. These settings will be applied to all the measurement data, either manually or automatically on opening.

To open the options window, select the **Tools→Options…** menu item. All the settings are explained below:

Units XY	Displays the in-plane dimensions in English (inches) or metric units (millimeters).
Units Z	Displays the out-of-plane dimensions in English (mils, 1 mil = 0.001 inches) or metric units (microns, or µm).
Smooth Phase on Open	Checking this box causes the phase image to be smoothed one time immediately after loaded.
Analyze on Open	Checking this box causes the measurement data to be analyzed immediately after loaded.
Grating Compensation	Checking this box applies compensation to all measurement data that contain compensation parameters (See **Section 4.4.2** for a discussion of grating compensation). It may be turned on or off for individual measurement data by right-clicking on a phase image and choosing **Advanced→Compensate**.

Normalize Chords	Checking this box causes all 2D chord plots to be displayed with the endpoints referenced to zero.
Default Rotation	Pull-down list sets the reference plane rotation to be applied during the analysis. See **Section 4.3**.
Gauges – Surface	Select which gauges (numerical values quantifying flatness) are Active. Activating a gauge means that it will be calculated and displayed in both the Displacement Window Gauges tab and at the bottom of any 3D graphs. A gauge on the list may be highlighted by clicking on it once. The up and down arrows move the highlighted gauge up and down the list, changing the order in which gauges are displayed.

Note: The second check box currently has no effect, and its value is not retained. It will have a use in future updates.

Gauges – Chord	Select which gauges show up at the bottom of a Chord Graph. Order By also determines the order in which the selected gauges are displayed.
Graphs	Selects which graph formats (see **Sections 5.1** through **5.4**) are displayed after analysis. A graph on the list may be highlighted by clicking on it once. Checking a box means that graph will be displayed. The up and down arrows move the highlighted graph up and down the list, changing the order in which graphs are displayed.
Configuration File	Allows the user to load a non-default display format for graphs. The 3D configuration file has an extension of *.akx_3Dconfig and is used for 3D plots. See **Section 5.1**. The 2D configuration file has an extension of *.akx_2Dconfig and is used for any 2D chords. See **Sections 5.3** and **5.4**.
Graph Size	Sets the initial size for all graphical displays created during analysis.
Gauge Display	Gauge values listed at the bottom of the 3D or 2D display window may be arranged horizontally or vertically.
Use Latest 3D View	Applies the perspective of the most recently modified 3D surface plot to all subsequently spawned 3D surface plots. In other words, if the user changes the altitude or rotation from which the surface is viewed in one graph, new graphs will automatically be shown from the same viewpoint. The zoom factor of the most recent graph will also be inherited.

Fixed Z-Scale When checked, this allows the user to adjust the data scale for all 3D or 2D plots. When unchecked, each image is plotted on a scale set by its own data set. This option is also available in Batch Analysis (**Tools→Batch Processing…→Analysis Tab**).

Batch Analysis Allows the user to load a *.akx_recipe file to change the default Batch Analysis settings. Also allows the default file format to be selected as well as whether the file full path is included in the batch results.

Create Report Allows the user to load a *.akx_ReportSettings file to change the default Create Report settings.

OK Any changes to the settings are saved and the window is closed.

Cancel The window will close without changes to the settings.

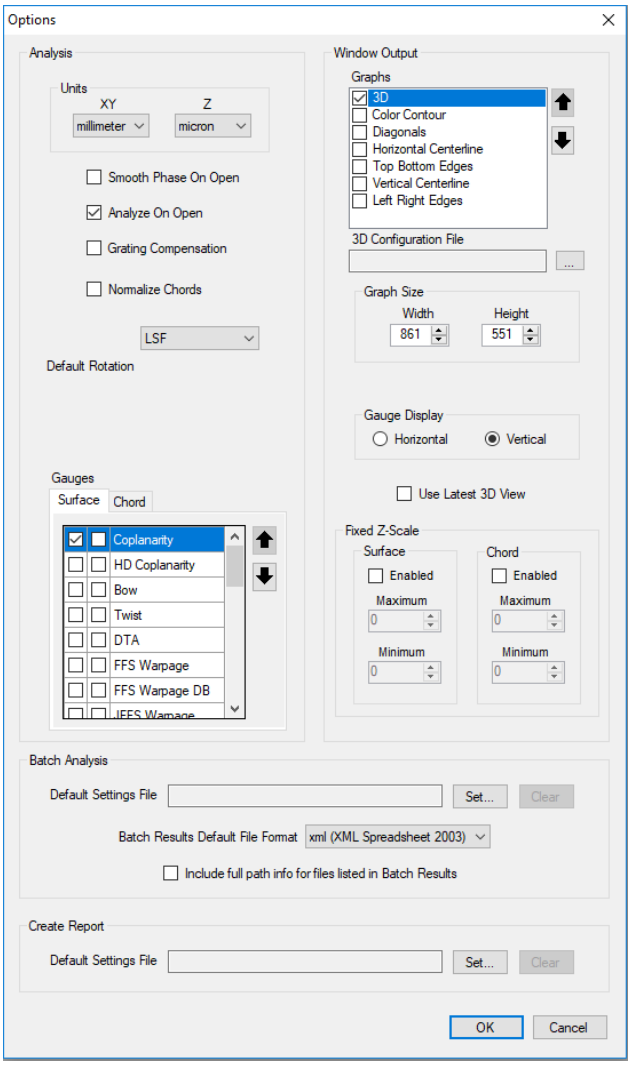


Figure 4.1 Options Window

Note: If no options are checked on the Graphs list, there will be no visible indication that analysis has taken place.

4.3 Reference Plane – Rotation

In order to display the displacement data, the user may define a coordinate system with a zero reference plane. This is especially useful when calculating gauges. To set the reference plane rotation to be used during analysis, select **Tools→Options…** and choose from the **Default Rotation** pull-down list.

The rotation choice can also be made before analysis by right-clicking on the phase image and choosing **Rotation** or **Transform→Plane Rotation** on a displacement image, then selecting from the list. The selected option is checked.

Note: The rotation option chosen in the options window will be applied to all the measurement data when loaded. The rotation option chosen from an individual phase or displacement image will only be applied to that particular data.

Surface Analysis provides the user with several options for defining the zero reference plane:

- **None:** The displacement data is not rotated and thus the reference plane is parallel to the grating. The zero value on the data does not correspond to any specific feature of the displacement surface.
- **LSF:** The displacement data is rotated so that the zero reference plane is the best fit plane calculated from all displacement points.
- **LSF Low 0:** LSF rotation option with the lowest displacement point set equal to zero (all others are positive displacement values).
- **LSF High 0:** LSF rotation option with the highest displacement point set equal to zero (all others are negative displacement values).
- **Three Point:** The displacement data is rotated so that the zero reference plane is defined by three corners (upper left, lower left, upper right).
- **Four Point:** The displacement data is rotated so that the zero reference plane is the best fit plane calculated from all four corners.

When analyzing a displacement image, the User Defined rotation option is also available. This allows the user to specify a region on the sample surface to fit a LSF plane to. This LSF plane is then used to rotate the entire surface.

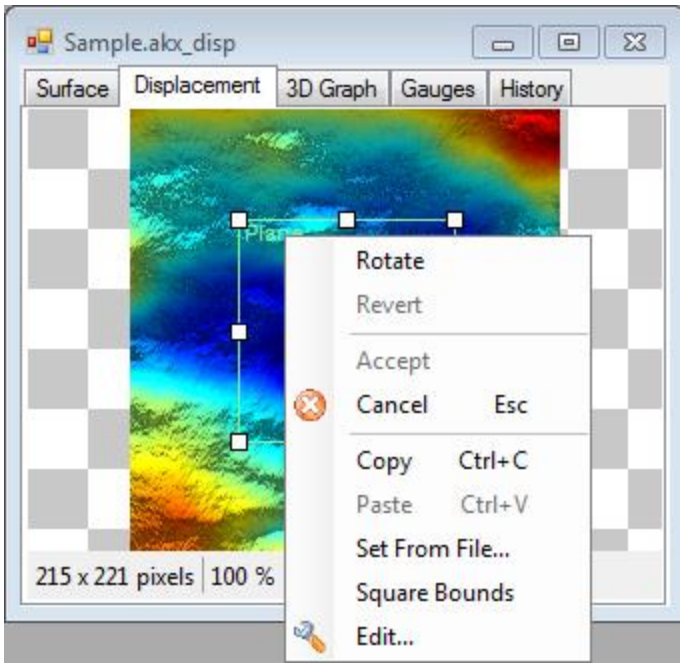


Figure 4.2 User Defined Plane Rotation

In **Figure 4.2** the green box can be dragged around and resized to cover the area that represents the desired rotation. In the context menu, Rotate will perform the rotation. If the rotation is deemed acceptable, Accept will complete the operation and remove the green box. Revert will undo the rotation. In addition, the green box can be copied from one displacement window to another using the Copy/Paste commands. Lastly, the box size and location can be set from another *.akx_disp file as well as edited using the Square Bounds and Edit commands.

The values of the individual data points change as a function of rotation (choice of reference plane), so gauges (e.g. coplanarity) and other calculated values are also a function of rotation. See **Akrometrix Optical Techniques and Analyses 101** for further discussion.

4.4 Reference Surface – Relative Displacement

A relative displacement measurement is calculated by taking the difference between two absolute displacement measurements. It is useful for observing the change in sample warpage as a function of sample history, temperature change, sample to sample variation, etc. The user interface to produce relative plots depends on how the input displacement data is loaded. See **Sections 4.4.1** and **4.4.2** below.

4.4.1 Phase Relative

When dealing with phase image derived displacement plots, there are two ways to produce relative plots. In the first, a baseline displacement surface is set to be the reference surface. Relative plots are then created from other phase images. In the second method, relative displacement surfaces are created with the displacement surface context menu.

To define a reference surface, right-click on a 3D graph analyzed from a phase image and check **Use as Reference** (**Figure 4.3**). This surface data can then act as a reference to all other displacement data. After identifying the reference surface, right-click on a second phase image of the same pixel dimensions. An additional menu item, **Analyze Relative**, appears on the list below **Analyze** (**Figure 4.4**). To obtain the relative displacement data, select **Analyze Relative**. The created relative surface is the current active surface minus the reference surface.

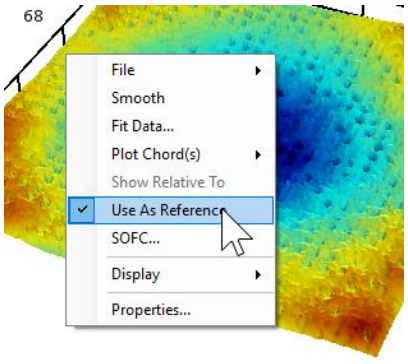


Figure 4.3 Use As Reference

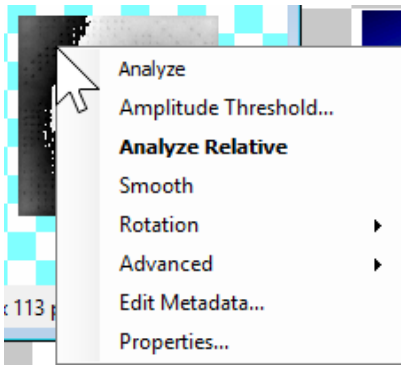


Figure 4.4 Analyze Relative

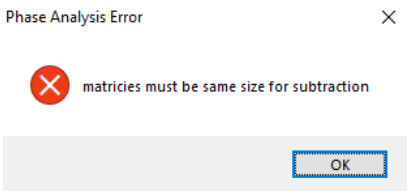


Figure 4.5 Mismatched Pixel Dimensions Error

Otherwise, choose **Analyze** to obtain the absolute displacement data. The relative displacement display can be turned off by right-clicking on the reference surface image and unchecking **Reference Surface**. Subsequently, **Analyze Relative** will disappear from the phase image context menu.

The second method for creating relative plots requires only interacting with the displacement context menu. Right click on the plot of interest and choose **Show Relative To**. A list of compatible surfaces is shown (**Figure 4.6**)

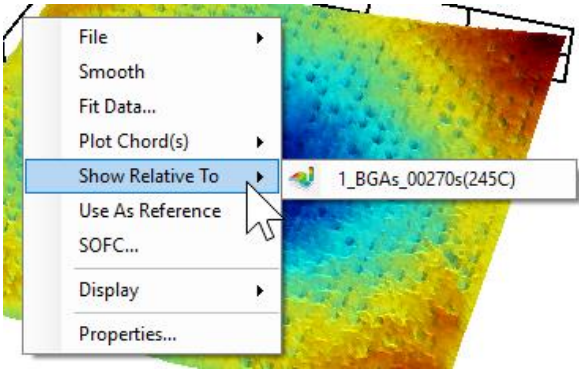


Figure 4.6 Show Relative To

Note: Relative plots produced from phase image displacement surfaces only compare data of the exact same pixel dimension. When using the **Analyze Relative** method, if the second phase image is of different pixel dimensions than the reference phase image, the user will be shown an error message (**Figure 4.5**).

4.4.2 Displacement Relative

When dealing with displacement images (loaded as *.akx_disp) the interface is changed. In the context menu, **Transform→Subtract** shows a list of open surfaces. Surfaces of the same pixel dimension are shown with a green checkmark. Surfaces of different sizes up to 4x different are shown with a yellow caution symbol. Surfaces greater than 4x different are grayed out and cannot be subtracted.

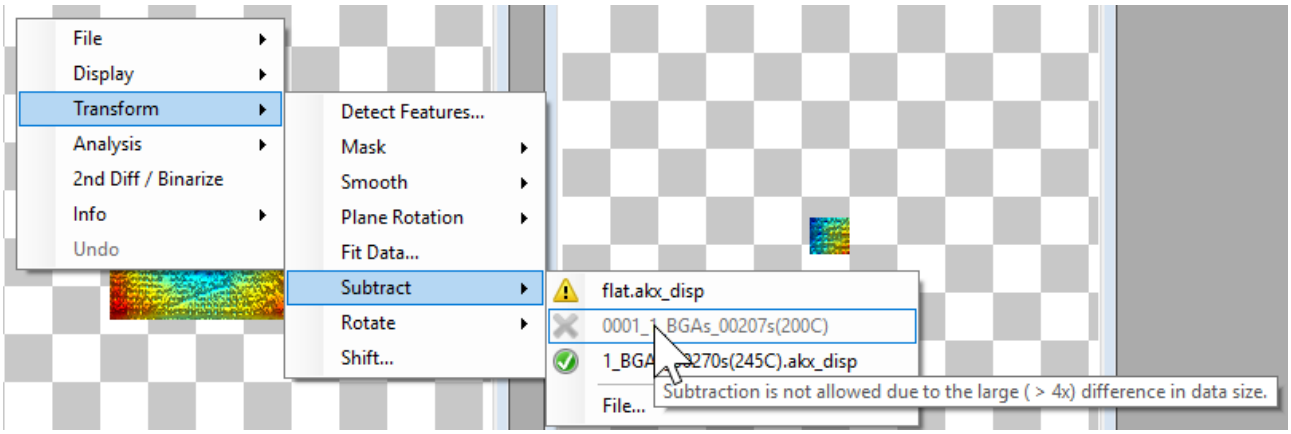


Figure 4.7 Displacement Relative Plot UI

If the user selects a surface of different pixel dimensions, the larger dimensions (in either image) will be shrunk down to fit the smaller dimension. A warning tells the user the resulting surface size (**Figure 4.8**).

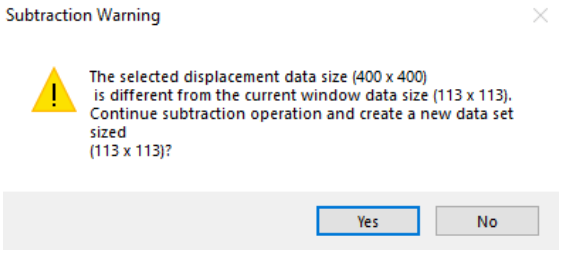


Figure 4.8 Subtraction Mismatched Size Warning

4.5 Reference Surface – Grating Compensation

The non-planar surface of a grating can be compensated by a reference surface (see **Akrometrix Optical Techniques and Analyses 101**). To enable grating compensation during analysis, check the **Enabled** box under **Grating Compensation** in the options window.

The compensation choice can also be made for individual phase images by right-clicking on the phase image and checking **Advanced→Compensation**. To turn off compensation, repeat the process and uncheck the selection by clicking it again.

Note: In the options window, the **Grating Compensation** option can be enabled or disabled regardless of whether the grating has been compensated or not. This option will be applied to all opened phase images that contain compensation data.

Note: The compensation option on an individual phase image will be grayed out if no compensation parameters can be found in the *.akx_phase file. Otherwise, this option is shown in black and can be checked or unchecked. The compensation option chosen for each phase image will only be applied to that particular image.

Note: In order to apply grating compensation, physical dimensions have to be assigned to the phase image (see **Section 2.3.5**). The grating compensation calculation assumes that the ROI is centered with respect to the grating. The accuracy of the compensation will be reduced if the ROI is not centered, particularly if it lies outside the central 4” by 4” area of the grating.

4.6 Unwrapping Parameters

A procedure called “unwrapping” is a key part of the analysis of measured phase data (See **Akrometrix Optical Techniques and Analyses 101**). The unwrapping process starts in the geometric center of the image and converts phase data to displacement values. Because the flood-fill algorithm used is inherently sequential, it simply stops any time a mask value is reached. As a result, it was impossible in previous versions of Surface Analysis to see data that was entirely separated by mask from the center of the surface being analyzed. An example of such data is shown in **Figure 4.3**. Only the center is analyzed because of the mask, which stops the unwrapping process from continuing to the valid surrounding data.

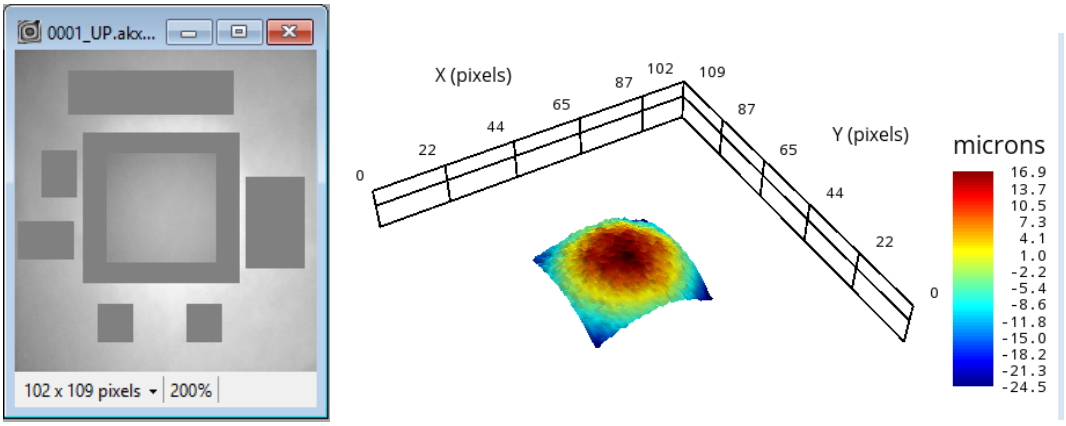


Figure 4.9 Isolated data

As of Studio 8.2, Unwrapping Parameters functionality allows the user to control aspects of the otherwise automated unwrapping process, thereby mitigating these data isolation issues. Unwrapping Parameters as a category covers two specific, mutually exclusive functions, Start Point and Phase Bridging, which solve the issue of isolated data in different ways.

4.6.1 Start Point

Start Point allows the user to manually change the start location of the unwrapping process, which, by default, starts in the center of the image. If only one isolated island of data is of interest, changing the start point allows the user to start the analysis in that island. **Figure 4.10** shows an example. Instead of starting in the center as in **Figure 4.9**, the same image is analyzed with the start point moved to a corner, and the previously inaccessible edges are now visible at the expense of the center.

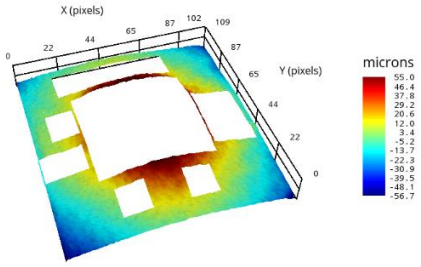


Figure 4.10 Analyzed Data with Altered Start Point

The key steps in editing a Start Point are:

1. Right click on the phase image and go to **Advanced→Unwrapping Parameters→Edit**.
2. In the resulting menu, change the X and Y location of the start point and select OK.
3. An orange dot will appear on the phase image, representing the new start point location. This can be toggled on and off using **Advanced→Unwrapping Parameters→Start Point**.
4. Analyze the file using the new Start Point.

4.6.2 Phase Bridging

Phase Bridging is a more complex solution to the issue of isolated data. With phase bridging, the user draws a bridge from one data "island" to another, so that the analysis software can bridge the gap. Unlike Start Point, Phase Bridging can be used to show all of the data at once. Examples of phase bridging are shown in **Figure 4.11** and **Figure 4.12**. Note that in **Figure 4.11** the data is all at a similar height, while **Figure 4.12** contains a step height which makes it difficult to see the fine scale warpage. Phase data is still used to calculate exact height from areas, although the height difference itself is entered manually for each bridge.

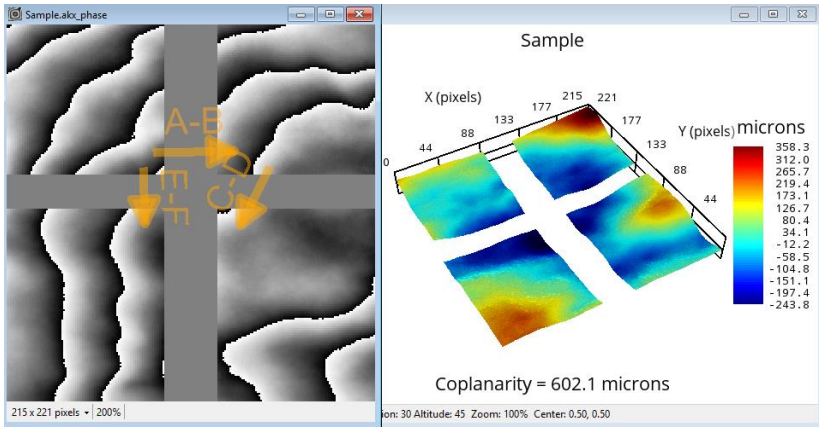


Figure 4.11 Phase-bridged Data at Similar Heights

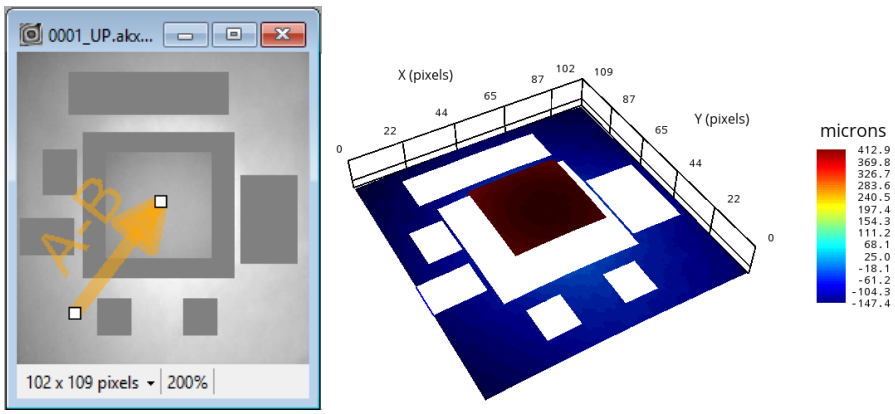


Figure 4.12 Phase-bridged Data with a Step

The key steps in creating a Phase Bridge are:

1. Right click on the phase image and go to **Advanced→Unwrapping Parameters→Add Bridge**, or press **Ctrl+B**.
2. Click on a start and end point in the phase image. Make sure to start in one data "island," and end in another.
3. As of Studio 8.3, Surface Analysis will then show a "Rotated" phase image where the data is shown relative to an LSF plane of the "A" phase region. This helps in determining where to place bridges and what height estimates to apply. Note that this is not the final data rotation as that is performed on the whole data set after unwrapping is complete.
4. An orange arrow will appear on the phase image, representing the new phase bridge. This can be toggled on and off using **Advanced→Unwrapping Parameters→Phase Bridging**
5. The user can add as many phase bridges as are necessary to connect all of the isolated data.
6. Analyze the file using the new Phase Bridge(s).

Note: Once a phase bridge has been added, unwrapping will begin from the beginning of the first phase bridge, and then start at the end of the bridge when that is complete, and so on across all phase bridges. This is why Start Point and Phase Bridging are mutually exclusive, and also why it is not possible to have multiple bridges leaving the same section of data. Bridges must move sequentially from section to section.

The user has a variety of options when it comes to editing and adjusting phase bridges. The start and end points of an existing phase bridge may be altered at any time by clicking and dragging the white handles at either end. In addition, right-clicking on an existing phase bridge brings up a unique context menu whose options are explained below.

Reverse Direction	Switches the start and end points of the phase bridge
Align	Aligns the phase bridge horizontally or vertically
Delete (Del)	Deletes the phase bridge
Edit	Brings up the Phase Bridge Edit Window shown in **Figure 4.13.**

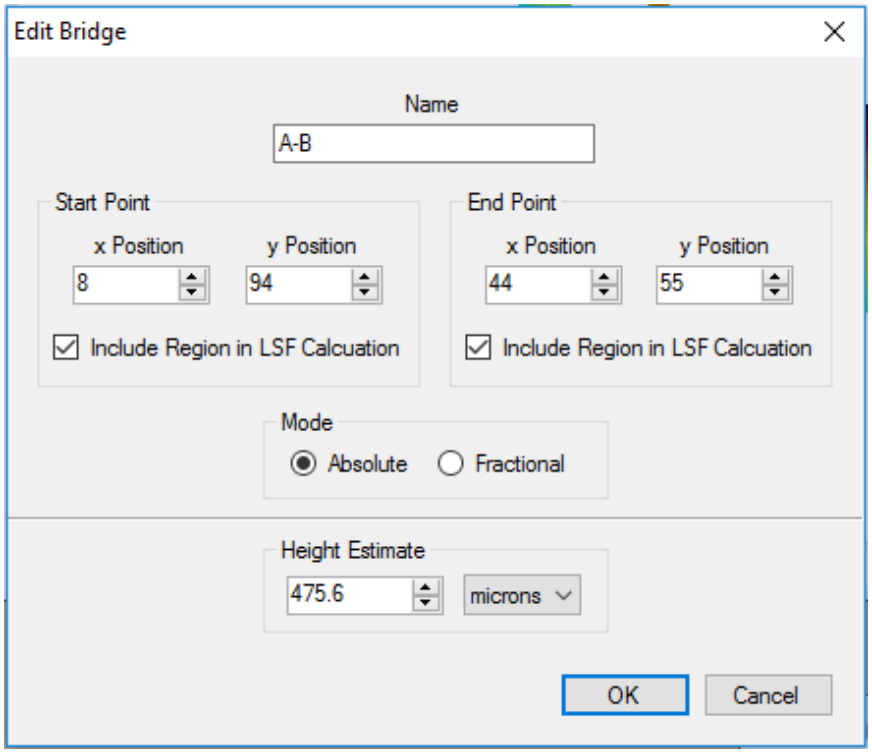


Figure 4.13 Phase Bridge Edit Window

The Edit Bridge window gives the user access to several powerful options for controlling phase bridges. These include:

Name	Change the name of the phase bridge. The default naming scheme for phase bridges is A-B, B-C, C-D, etc.
Start Point	Determines the coordinates of the start point of the phase bridge.
End Point	Determines the coordinates of the end point of the phase bridge.
Include Region in LSF Calculation	Selecting this option includes a given region when an LSF plane calculation is performed on the data (see **Section 4.3**).
Mode	Determines whether the coordinates of the start and end points are expressed in absolute or fractional mode.
Height Estimate	The user-entered height estimate is used by the program to determine the relative height of bridged sections. Since phase data is relative, the program doesn't treat a connected section a different fringe order unless the user tells it to. The user height estimate determines the fringe order of the isolated section while the actual phase data is used for fine scale height within that fringe order.

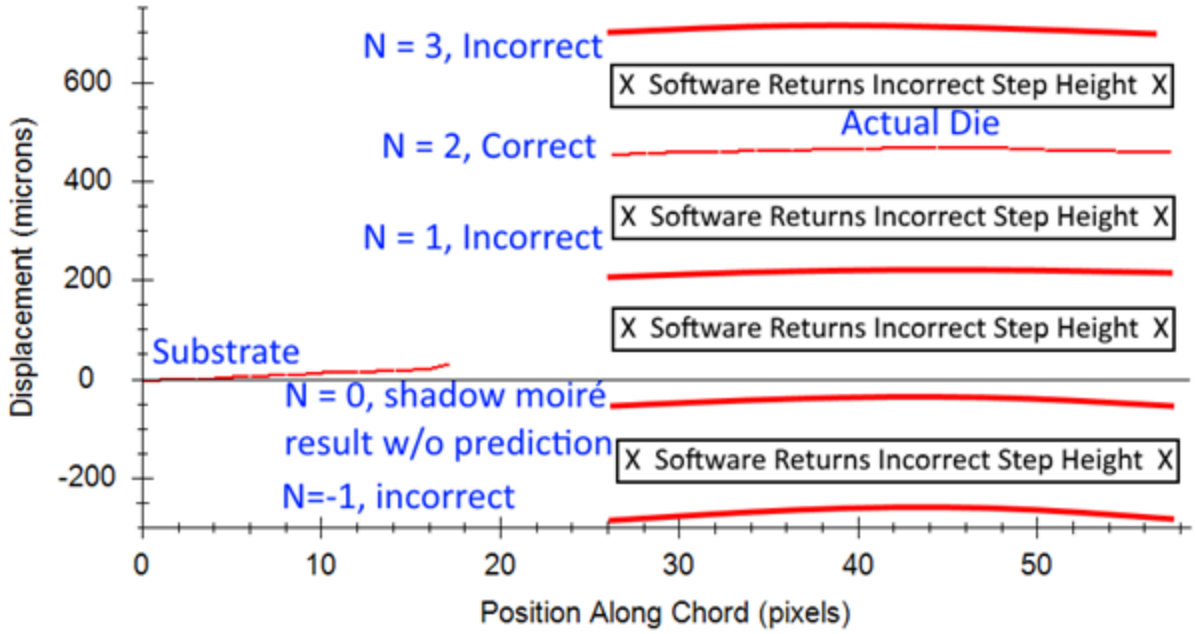


Figure 4.14 Phase Bridge Step Height Example

Note: Height estimates must fall within +/- 0.25 Fringe Values of the measurement (+/-64 microns with the 100 LPI). Height Estimates incorrect by +/- 0.25 to 0.75 Fringe Values will generate an error from the software stating an incorrect height estimate. Height approximations incorrect beyond this threshold would lead to incorrect data. This is illustrated in **Figure 4.14** using the same data set from **Figure 4.12**.

4.6.3 Second Diff Quality Mapping

Standard phase unwrapping occurs via a flood-fill algorithm that starts in the center of the image. This process can lead to unwrapping errors when phase quality is poor. The second differences quality mapping routine ranks the quality of the phase, pixel by pixel and follows a path that starts with the highest quality phase data and moves towards the lowest. It will preferentially follow an unwrapping path that avoids larger changes in slope. In cases with random noise in the phase, this can result in significantly reduced unwrapping artifacts.

This function can be activated by right-clicking on a phase image and going to **Advanced→Unwrapping Parameters→Second Diff Quality Mapping**. When it is enabled, a **Threshold** must also be entered where higher values lead to more low quality phase pixels being removed. Typical values range between 900 – 1000.

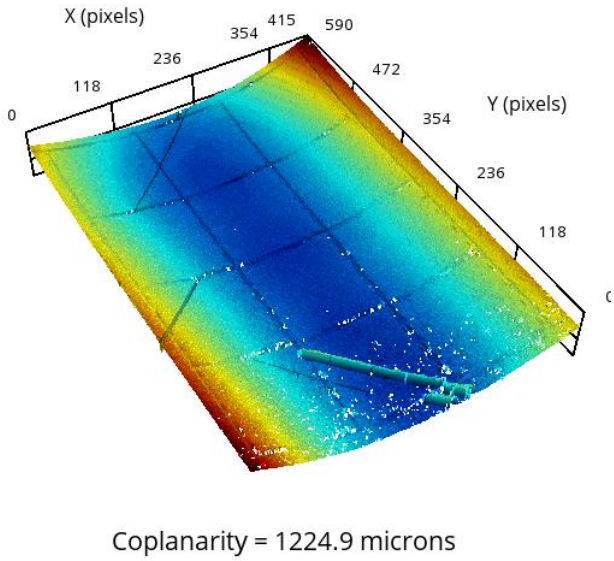


Figure 4.15 Standard Flood Fill Algorithm Unwrapping with Artifacts

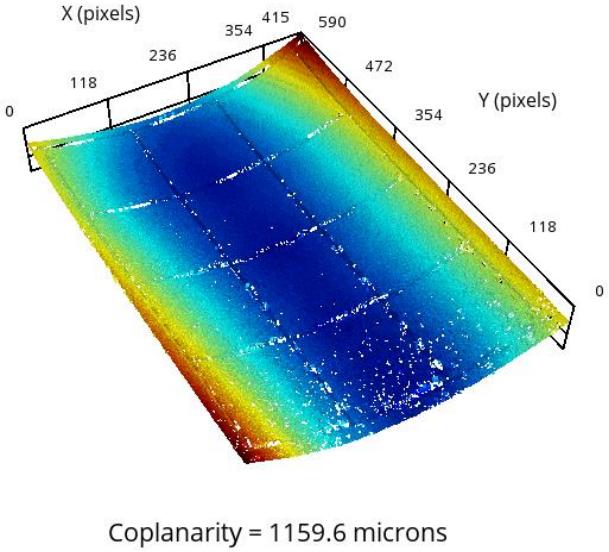


Figure 4.16 Second Differences Unwrapping without Artifacts

4.6.4 Unwrapping Parameter Files

Once unwrapping parameters have been set, they can be copied or saved to be used in other files. From the **Advanced>Unwrapping Parameters** context menu, the user can:

- Load existing *.akx_unwrap files.
- Save any active unwrapping parameters as *.akx_unwrap files.
- Copy any active unwrapping parameters.
- Paste copied unwrapping parameters onto phase images.

Note: In this context, “active unwrapping parameters” are those that are toggled on in the context menu and visible in orange on the phase image.

5 Displaying Results

After analysis, the information is displayed in a choice of four graphical formats:

- 3D Surface (**Section 5.1**)
- 3D Contour (**Section 5.2**)
- 2D Diagonal (**Section 5.3**)
- 2D Chord (**Section 5.4**)

The data displayed in each graph can be exported in numerical form (**Section 5.5**). In the meantime, gauges (single values representing the warpage) can be displayed at the bottom of the 3D graphs (**Section 5.6**).

5.1 Graphical Output – 3D Surface Plot

5.1.1 3D Display Window

To display the 3D Surface plot after analysis, check the box next to **3D** on the **Graphs** list in the options window (**Section 4.2**). After right-clicking and selecting **Analyze** on the phase image or **Analysis→Generate Results** on a displacement image, a new 3D display window is opened and the 3D height map represented in color is shown in the center of this window. Interaction with the 3D display when generated from a displacement image is similar to that of the original image. Further details on the 3D display window generated from a phase image are discussed in this **Section 5.1.4**. The name of the data file will be shown on the top and gauges selected in the options window will be displayed below the 3D image. The caption of the 3D display window can be renamed by right-clicking on its title bar and selecting **Rename Window…**. Additional information including cursor coordinate position, viewpoint and zoom ratio can be found in the status bar at the bottom left. See **Figure 5.1**.

5.1.2 Key/Mouse Interactions with the Graph

There are five interactions that can be done with the 3D graph:

1. **Coordinates** of each individual data points are shown live in the status bar by hovering the cursor over the 3D image.
2. **Rotate** adjusts the angle from which the surface is viewed. Press the left mouse button and drag the plot to the desired orientation in the display window. The current Rotation and Altitude parameters will be displayed in the status bar.
3. **Zoom** adjusts the scale of the plot. Scroll the mouse wheel and change the plot to the desired scale in the display window. The current 3D graph magnification level will be displayed in the status bar.
4. **Pan** adjusts the plot center point. Simultaneously press the Ctrl key and left click on the plot to set the center point. Subsequent rotate and zoom functions will rotate and zoom about this new point.
5. **Esc** key brings the 3D graph back to its original size (zoom ratio of 100%) and center point.

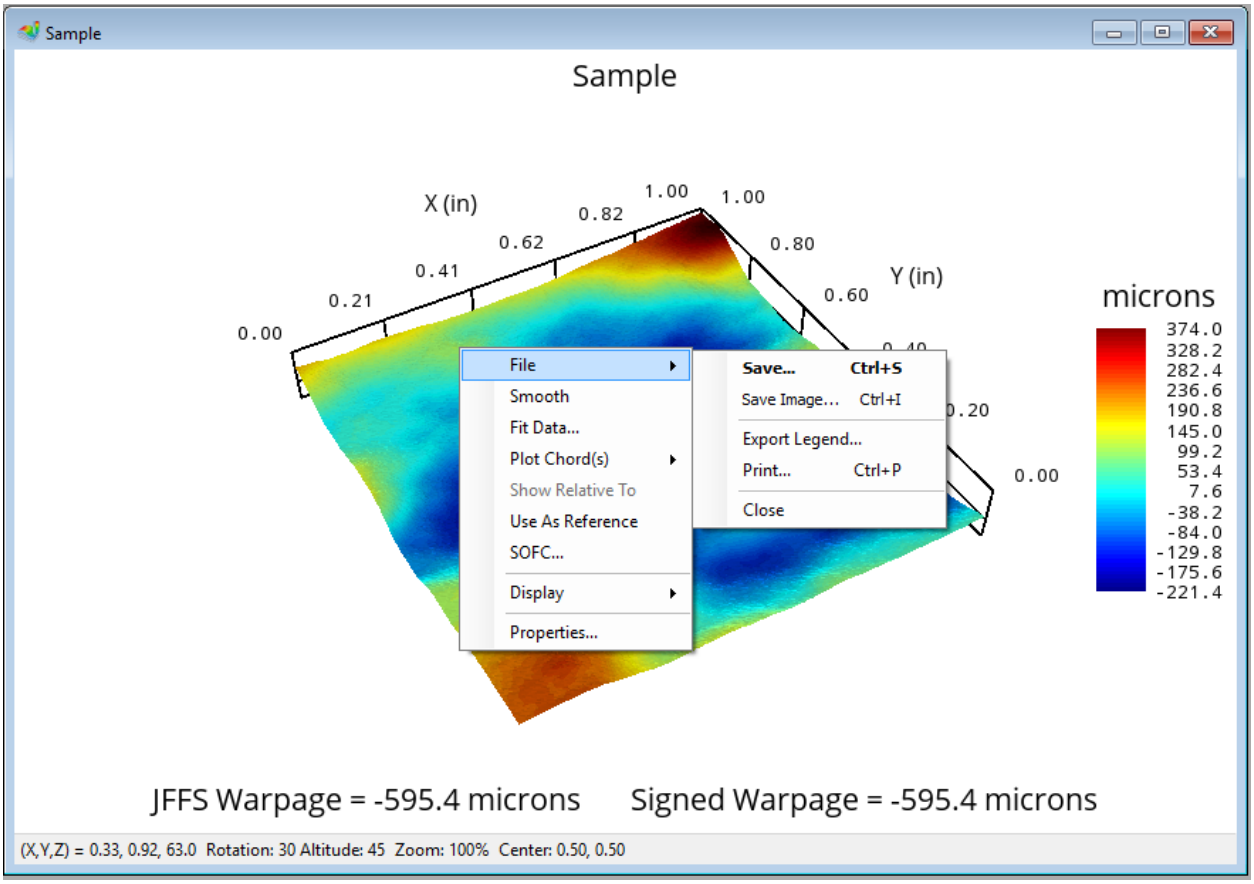


Figure 5.1 3D Surface Plot

5.1.3 Changing Viewpoint

The viewpoint of a 3D graph can be set using four different approaches:

- **Use Latest 3D View** box in the options window (**Section 4.2**)
- **Rotate** and **Pan** operations (**Section 5.1.2**)
- **Copy View** and **Paste View** in the 3D display command list (**Section 5.1.4**)
- The display **Configuration** window (**Section 5.1.5**)

5.1.4 Graph Command List

Right-clicking on the display window will show a different context menu depending on whether it came from a phase image or a displacement file. The context menu for a 3D graph created from a phase image is described below. For 3D graphs originating from a displacement window, the context menu command list is the same as that on the 3D Graph tab in the multi-tabbed *.akx_disp window. See **Section 2.4**.

File — Allows saving of the current displacement data either numerically or as a picture. Also contains commands for exporting a legend, printing the picture and closing the window.

Smooth	Applies a smoothing function to the 3D data and shows the smoothed surface in a new window. This command can be repeated multiple times. See **AOTA101** for more information.
Fit Data…	Opens a dialog where a polynomial fit can be calculated based on the data set. See **Figure 5.2**. Alternatively, if physical dimensions are assigned to the phase image, a spherical fit can be calculated.
Plot Chord(s)	Plots pre-defined chords in a new window.
Show Relative To	Displays the relative displacement data calculated by subtracting a selected 3D data from the current 3D data in a new window.
Use as Reference	Sets the current 3D data to serve as the reference surface
Invert	Inverts Z data
SOFC…	Displays a window containing all Second Order Fit Coefficients used to calculate a 2nd order polynomial fit for the surface. As of Studio 8.5, this list also includes the coefficient of determination, denoted R^2 (R squared).
Display	Contains the copy, paste, and reset view commands for applying one 3D graph orientation and zoom to another. Also contains Z-Axis units, scale options, and a switch to show Pin 1 Location on plots. Lastly, graph configuration parameters are accessed here. See **Section 5.1.5**
Properties…	Opens a displacement object properties window with all saved parameters relating to the displacement object.

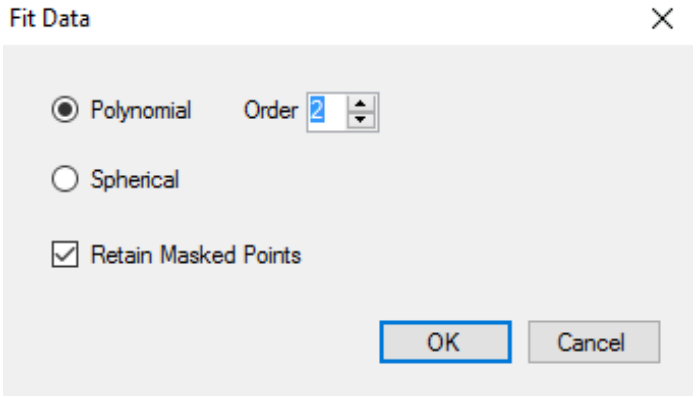


Figure 5.2 Fit Data Dialog

5.1.5 Display Configuration Window

The display configuration window (**Figure 5.3**) gives the user the ability to customize the graph display format. The custom format can be saved and re-used, and set as the

default format for all 3D plots. To display the configuration window, right-click inside the graph window and select **Configure…**.

In the configuration window, to load a previously saved display configuration, choose **File→Open…** (**Ctrl+O**). To save the current display configuration, choose **File→Save….** (**Ctrl+S**).

Note: The display configuration file (*.akx_3Dconfig) loaded from the display properties window is applied to the current display window (**Figure 5.1**). Configuration files loaded from the Options window (see **Section 4.2**, **Figure 4.1**) will be applied to all newly created display windows.

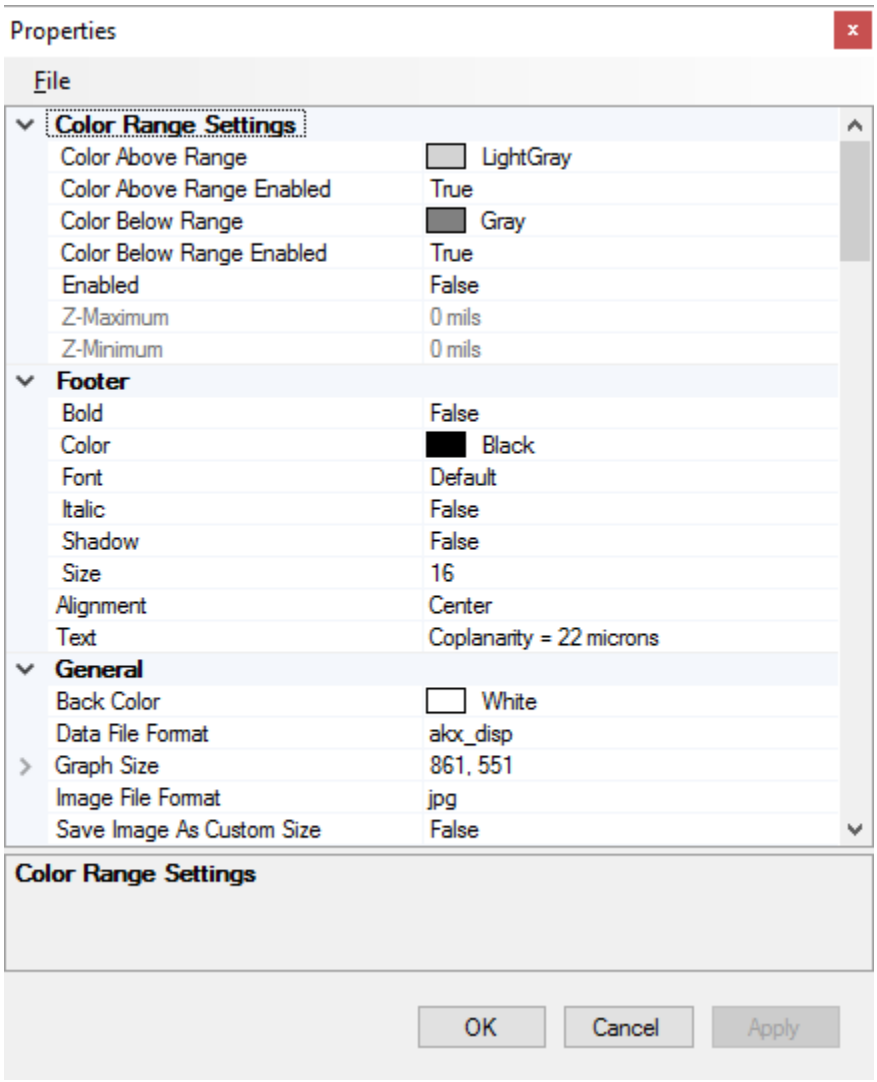


Figure 5.3 Display Configuration Window

5.2 Graphical Output – 3D Contour Plot

To display the 3D Contour plot after analysis, check the box next to **ColorContour** on the **Graphs** list in the options window. Most of the contour plot commands and features are identical to those described in **Section 5.1** (**Figure 5.4**).

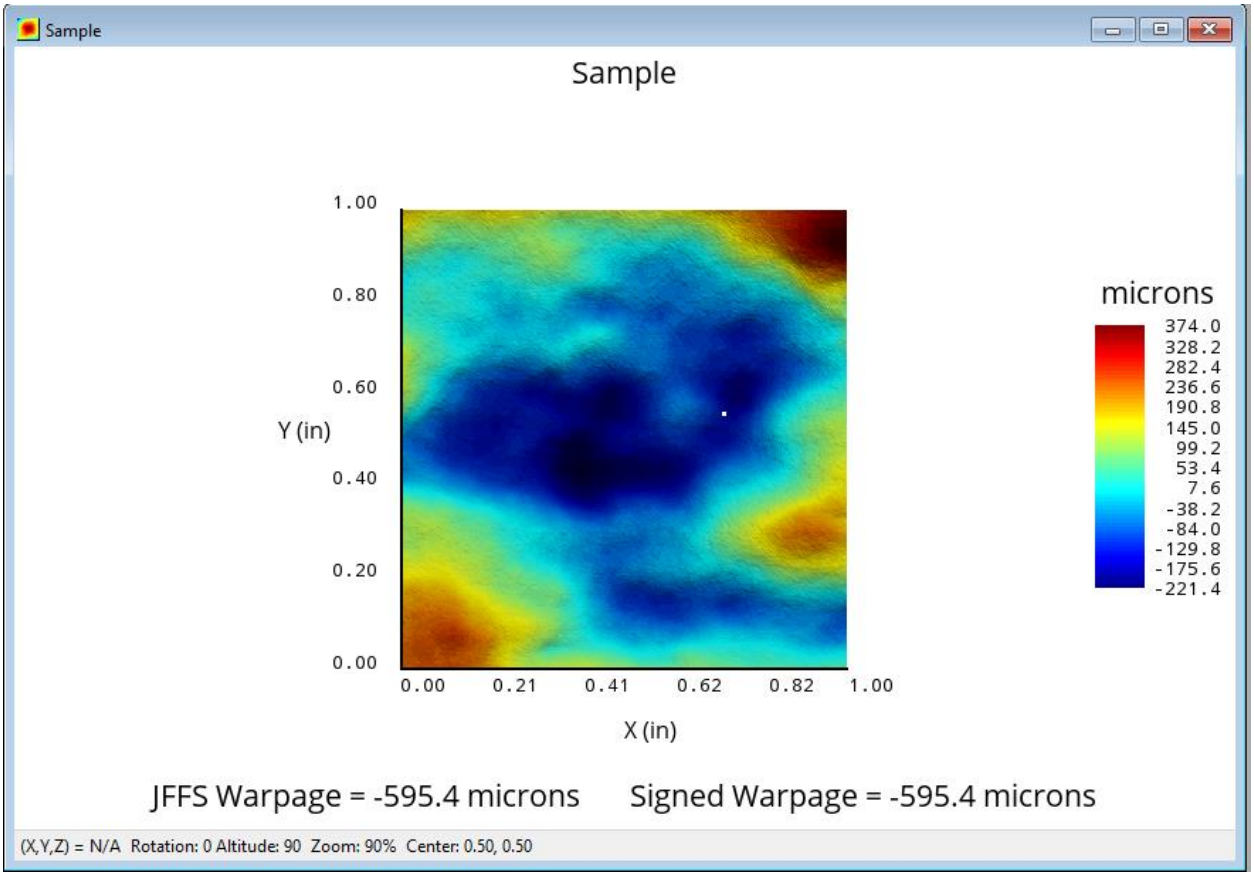


Figure 5.4 Contour Plot

5.3 Graphical Output – Default Chord Plots

A chord is a 2D line across the surface of a part. A chord plot graphs the z-values along these lines. Surface Analysis can display a wide variety of plots for both default and custom chords. The most common default chords are Diagonals, Horizontal Centerline, Vertical Centerline, Top Bottom Edges, and Left Right Edges. These common chords are all available on the **Graphs** list in Tools>Options, and checking them there causes these chord plots to come up automatically when analyzing a phase image.

Note: The diagonal plot (**Figure 5.5**) represents two cross-sections of the surface along diagonal lines connecting the corners.

The plot window for any of these common chord plots, along with some other default chords, can also be opened by right-clicking on the 3D display window and selecting **Plot Chord(s)→Chord Name**. A full list of available default chords is below.

- Diagonals

- Centerlines
- Top Bottom Edges
- Left Right Edges
- All Edges
- All Edges Centers Diags
- Five Vertical
- Five Horizontal
- Horizontal Centerline
- Vertical Centerline

Note: All of the chords oriented horizontally are plotted from left to right and all vertical chords are plotted from top to bottom.

Note: The caption of the 2D display window can be renamed by right-clicking on its title bar and selecting **Rename Window…**.

Note: On the 3D Graph tab of a displacement file, **Analysis→Plot Chord(s)→Chord Name** will bring up a chord plot.

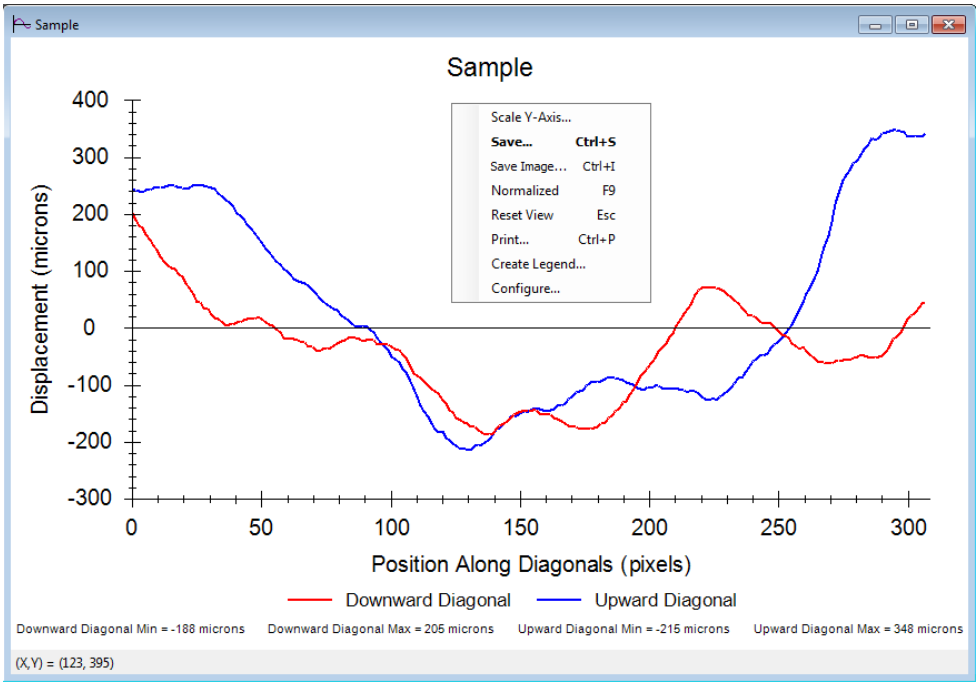


Figure 5.5 Diagonal Plot

5.3.1 Display Command List

Right-click inside the display window to show the command list.

Scale Y-Axis…	Displays a window where the minimum and maximum values of the Y axis may be modified. Defaults are the min and max values of the data plus a software determined buffer.
Save…	Exports the data in numerical format (**Section 5.5**)
Save Image…	Allows display window to be saved in graphical format (*_dia.png).
Normalized	Causes all diagonal plots to be displayed with the endpoints for each diagonal set to zero.
Reset View	Resets the graph view after it has been zoomed.
Print…	Allows display window to be printed to any available system printer.
Create Legend…	Allows the legend to be saved as a separate picture file for reporting purposes.
Configure…	The 2D display properties window is very similar to the 3D version described in **Section 5.1.5**.

5.4 Graphical Output – Custom Chord Plots

In addition to the default chords described in **Section 5.3**, arbitrary chords or chord sets can be defined, where out-of-plane displacement data along any line(s) can be displayed. The following subsections will describe how to draw a generic chord or chord set.

5.4.1 Creating a Chord

Right-click inside a phase image and select **Advanced→Chord→Add Chord… (Ctrl+K)**. Using the mouse, draw a line across the image, holding down the left mouse button at the start point and releasing it at the end point.

Note: Chords can also be plotted on 2D displacement images (*.akx_disp files). The menus and functionality are the same, but the Chord Menu is found under **Analysis→Chord**. The rest of this section will use the terminology for phase images.

Several preset chords can be added to the phase or displacement image using keyboard shortcuts.

- **Shift+T**: Top Edge
- **Shift+B**: Bottom Edge
- **Shift+L**: Left Edge
- **Shift+R**: Right Edge
- **Shift+D**: Downward diagonal (upper left to lower right corner)
- **Shift+U**: Upward diagonal (lower left to upper right corner)
- **Shift+H**: Horizontal centerline
- **Shift+V**: Vertical centerline

Note: Preset chords can be removed by hitting the keyboard shortcut a second time. They cannot be edited.

5.4.2 Editing and Plotting Chords

To reposition the endpoints of a chord, click on the chord. Square white handles will appear on either end of the chord, which can be moved with the cursor.

Right-click on a chord to show the chord command options list:

Edit…	Allows the endpoint positions to be set to specific pixel values using text boxes. Also allows renaming of the chord.
Plot	Plots all selected chords in a new 2D display window.
Plot Set	Plots all chords appearing on the phase or displacement image (only available when more than one chord is shown on the image).
Reverse Direction	Reverses the direction of the data along the chord when plotted. Works on all selected chords.
Align	Aligns the chord horizontally or vertically. Works on all selected chords.
Delete (Del)	Deletes all selected chords.
Delete All	Deletes all chords.

When **Plot** or **Plot Set** is chosen, calculation is performed and a display window appears. All display commands available for Diagonal plots are applicable here, including exporting the chord displacement data in numerical form (**Section 5.3.1**).

5.4.3 Using a Chord Set

One or more chords form a set, which can be saved, re-used, and plotted collectively. A set is started automatically when the first chord is drawn on the phase or displacement image. Additional chords added using **Advanced→Chord→Add Chord** become part of this set.

A set can be saved by right-clicking on the phase image and choosing **Advanced→Chord→Save…** and a saved set can be loaded by choosing **Advanced→Chord→Load…(Ctrl+Shift+K)**. A saved set has a filename ending in *.akx_chordset. These files can be loaded in batch analysis and report creation as well as on individual phase or displacement images.

Note: If a loaded chord set was generated from a larger phase or displacement image than the current one, only the chords with both ends falling within the current image in that set will be loaded.

A chord or set of chords can be made visible or invisible by going to **Advanced→Chord→Visible**. **Advanced→Chord→Locked** prevents moving or interacting with chords.

5.4.4 Saving a Chord Image

After a chord or chord set is plotted, the graphical image can be saved by right-clicking on the 2D image and choosing **Save Image…**. The image may be saved in PNG format with different suffixes as listed below:

Chord Type	File Suffix	File Extension
Diagonal	_dia	.png
Horizontal Centerline	_hzc	.png
Horizontal Edges	_hze	.png
Vertical Centerline	_vtc	.png
Vertical Edges	_vte	.png
Arbitrary	_crd	.png

5.5 Numerical Output

Numerical data from all display windows can be exported from the context menu. For any 2D plot, this is done by right-clicking on the display window and selecting **Save…**. A standard **Save** window appears with multiple choices for the save format in the **Save as type** pull-down list at the bottom. 3D plots – Color Contour and 3D graph – have slightly different context menus and save options, as described in **Section 5.1.4**.

Akx_disp Exports data in the Akrometrix akx_disp format (not available for chords)

Dat files Exports data in tab-delimited text format

Text files Exports data in space-delimited text format

Dat and text files containing chord data will use the same prefixes as chord image files, as described in **Section 5.4.4**.

5.6 Gauge Output

Gauges can be selected in the **Gauges** list in the Options window and are displayed at the bottom of 3D Surface, Contour or Chord plots where appropriate. Gauge definitions are available in **Akrometrix Optical Techniques and Analyses 101**.

6 Interface Analysis

Utilizing individual surface data captured separately, Interface Analysis (IA) is a feature designed to analyze and display mating surface measurements produced by Akrometrix warpage measurement systems. IA places 3D plots on top of each other in order to visualize and quantify the gaps that might exist across the interface. Gap pass-fail warning maps can be generated which highlight interconnect areas that would possibly fail. IA functionality can be accessed in two different workflows: a one-off mode for quick comparison (see **Section 6.3**), and a batch function (**Section 6.4**) for many sets of surfaces over a temperature profile.

6.1 Orientation and Registration using IA Metadata

In order to properly orient the two surfaces being analyzed, the following metadata fields are introduced.

1. Pin 1 Location: Which of the 4 corners of the measured surface is Pin 1
2. Inner Surface: The attach side of a BGA or PCB in an interface stack of interest
3. Outer Surface: The non-attach side (e.g. mold compound or top side) of a BGA, or the side opposite the attach location for a PCB in an interface stack of interest
4. Top Part: A part that would physically be located on the top of an interface stack of interest during the temperature cycling process
5. Bottom Part: A part that would physically be located on the bottom of an interface stack of interest during the temperature cycling process

Defining the interface stack of interest is crucial to setting up Interface Analysis correctly. In a typical electronic package assembly, there are only single interface stacks of interest. The most common of these scenarios is a BGA device on a PCB as in **Figure 6.1**.

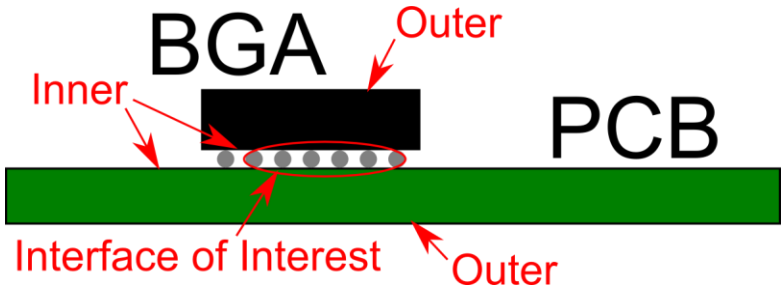


Figure 6.1 BGA on PCB Interface Stack

There are other package assemblies where there might be multiple interface stacks which affect whether a specific surface is defined as inner vs outer or top vs bottom. In **Figure 6.2** and **Figure 6.3** below, the sandwiched substrate can be defined as both top or bottom, and inner or outer depending on which interface is being studied.

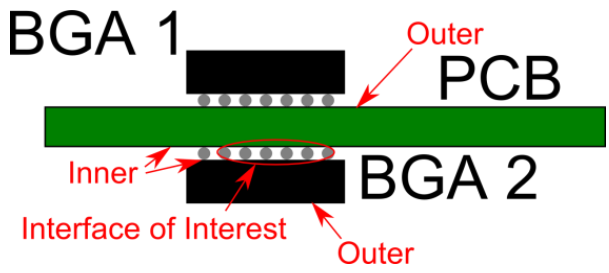


Figure 6.2 BGA's on both sides of a PCB

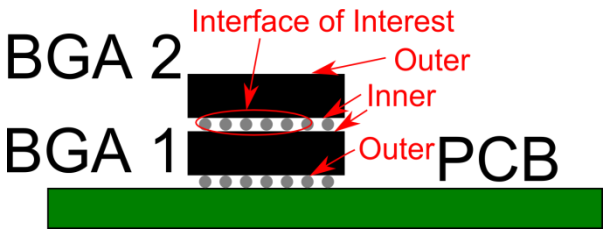


Figure 6.3 PoP on a PCB

If the top interface is studied in **Figure 6.2**, then the top surface of the PCB would be considered an inner surface. If the bottom interface were studied, then this same surface would be considered outer. Similarly, the surfaces on the sandwiched BGA in **Figure 6.3** could vary depending on the interface of interest. When studying the interface between BGA 1 and BGA 2 in **Figure 6.3** the top side of BGA 1 is now considered an inner surface, along with the bottom side of BGA 2.

Once the interface of interest has been determined, and the inner/outer and top/bottom assignment been made, the software can rotate and/or flip the data so that the pin 1 locations on each surface mate up. If the inner surface of a top part is being analyzed, the software flips the data, and then rotates it such that pin 1 matches up. If the outer surface of that same part is measured, the data is not flipped. Flipping or not flipping the data will occur according to the combinations shown in **Table 6.1**. After the data has been flipped, the software will rotate each surface such that pin 1 is in the same corner for both top and bottom surfaces.

Table 6.1 Surface Type Flip vs No Flip

	Inner	**Outer**
Top	Flip	Don't Flip
Bottom	Don't Flip	Flip

When data is gathered in Surface Measurement or analyzed in Surface Analysis, the Pin 1 Location, Measured Side, and Interface Location of the part surface can be specified. Together, this orientation metadata information is critical to Interface Analysis in analyzing and orienting the data sets.

6.2 Offset Methods

Another important option when analyzing the interface between two surfaces is how the surfaces are offset from one another. The measured gap will be greatly influenced by this offset method choice. Interface Analysis offers the following offset methods:

6.2.1 Closest Point Touching

The Top and Bottom surfaces are brought together with their LSF planes parallel until the first point touches. An example, utilizing the Maximum surfaces from **Figure 6.25** and **Figure 6.26** is shown below.

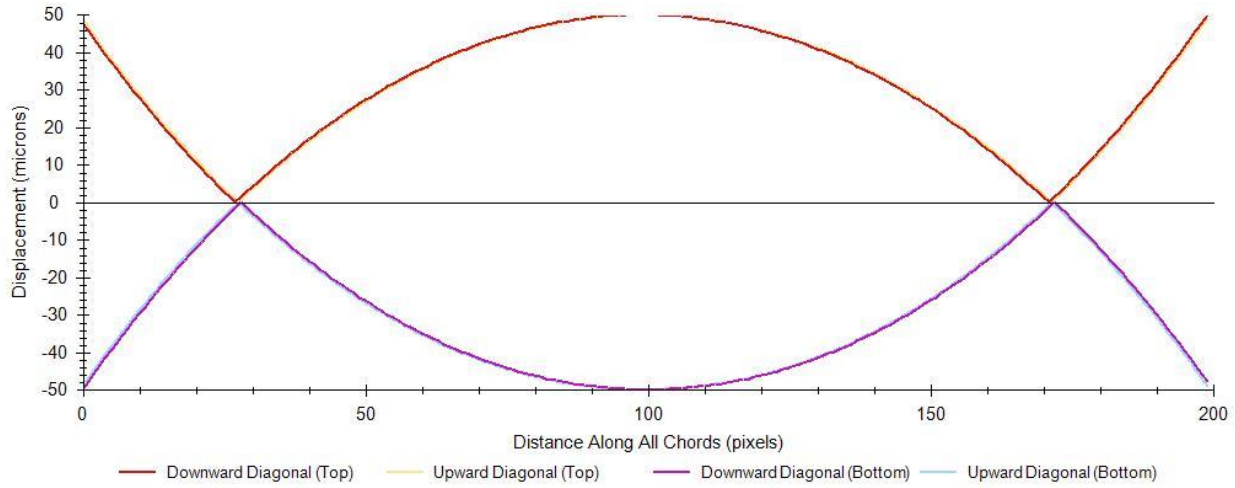


Figure 6.4 Example Diagonals of Closest Point Touching Offset Method

6.2.2 Closest Point Offset

This offset method is the same as Closest Point Touching but with a user defined value added to account for solder ball height or other attachment interface material.

6.2.3 Center Gap Constrained

A 10 x 10 pixel area in the center of the top surface is averaged. This average value is then offset by a user defined amount from a similarly calculated average value on the bottom surface. In the example below, the offset was chosen to be 0.

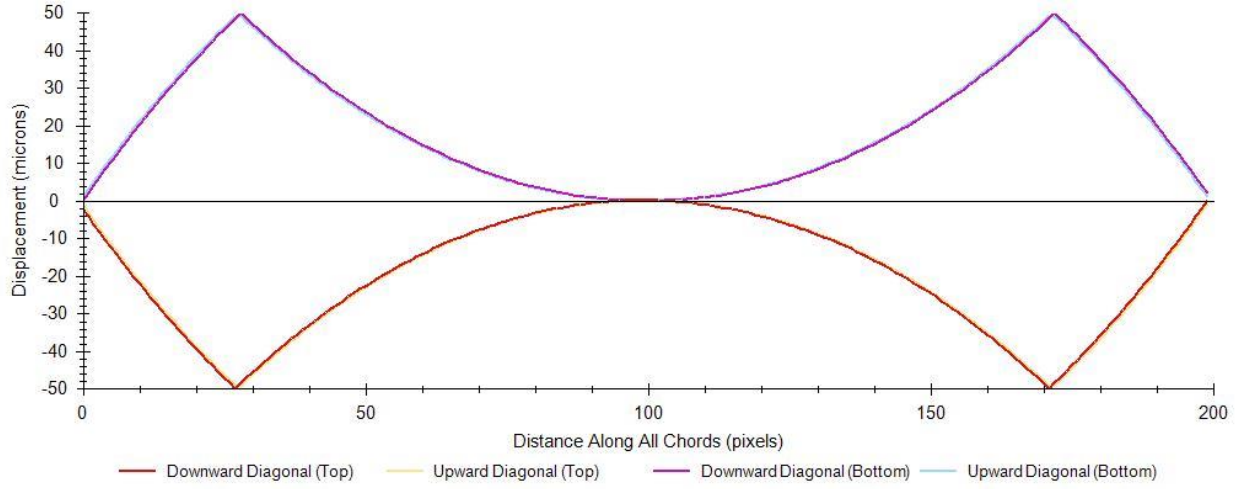


Figure 6.5 Example Diagonals of Center Gap Constrained Offset Method

6.2.4 Edge Gap Constrained

An average edge value is calculated from all the edges on the top surface. This average value is then offset by a user defined amount from a similarly calculated average value on the bottom surface. In the example below, the offset chosen was 0.

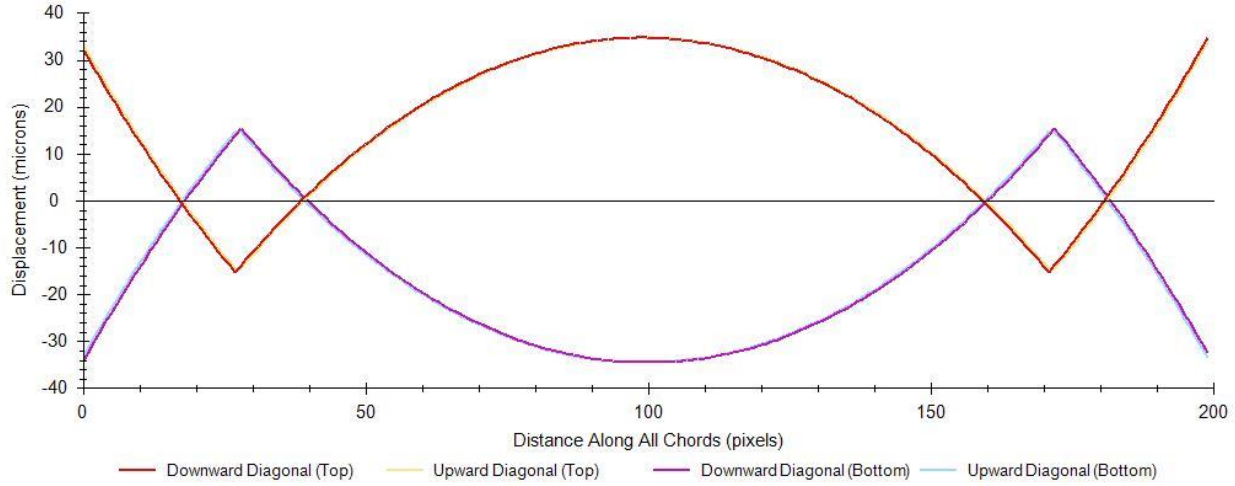


Figure 6.6 Example Diagonals of Edge Gap Constrained Offset Method

6.2.5 Datum Plane Fixed

The Least Squares Fit High 0 and Low 0 planes for Bottom and Top surfaces are aligned and set to the same Z height in this offset method.

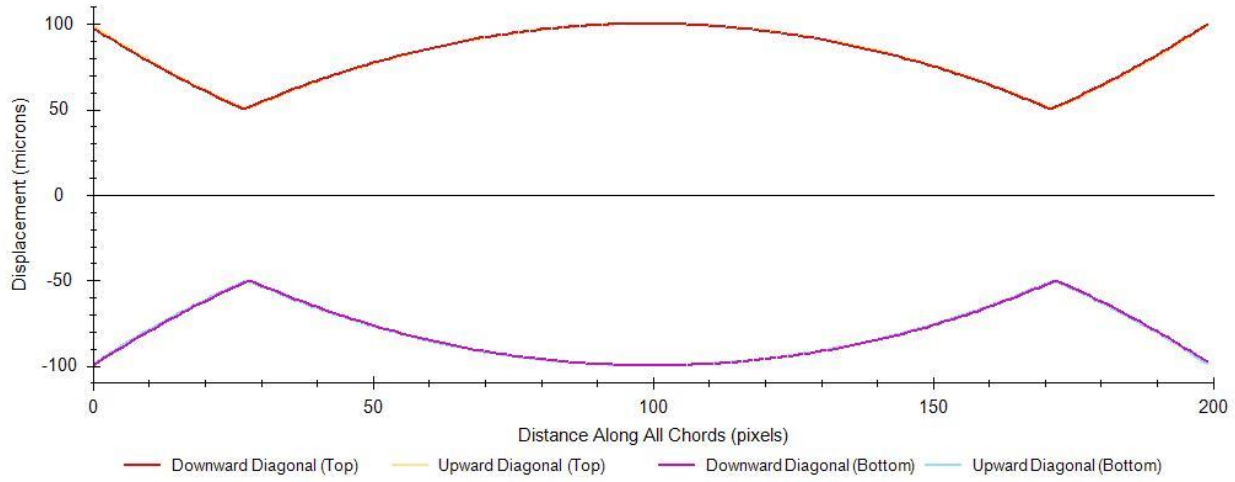


Figure 6.7 Example Diagonals of Datum Plane Fixed Offset Method

Note: Datum Plane Fixed is most useful in Batch IA when any significant shape change has occurred in either the Top or Bottom statistical group of surfaces. By using this method, even if the resulting average surface looks nothing like a real surface, the gap at any particular point will still be valid.

6.2.6 Datum Plane Offset

This offset method is the same as Datum Plane Fixed but with an additional user defined offset.

6.3 One-Off Interface Analysis

Under the Analysis section of the displacement window context menu, Interface Analysis can be chosen among a list of other open displacement images. Image size mismatch is noted in parentheses next to each entry with a green check mark, yellow triangle, or red X denoting how reasonable the size agreement is. Displacement images not currently open can be opened by selecting the **File…** menu item at the bottom (**Figure 6.8**) and browsing to the file on disk.

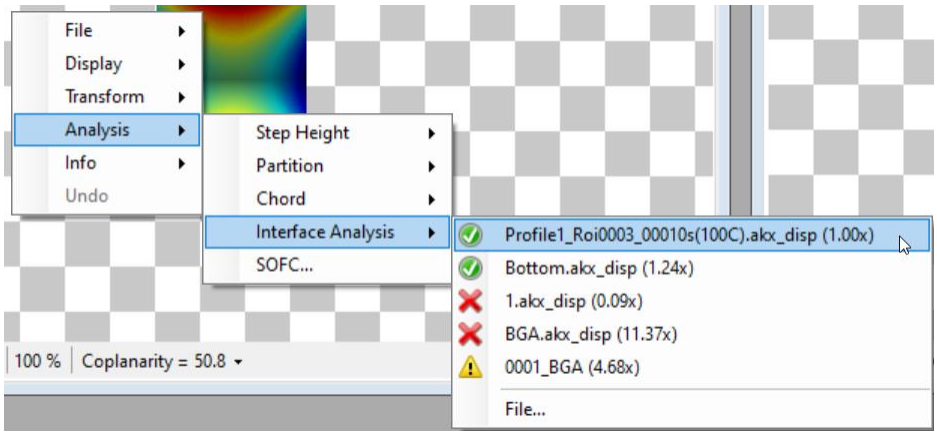


Figure 6.8 Selecting a file for Interface Analysis - One-off

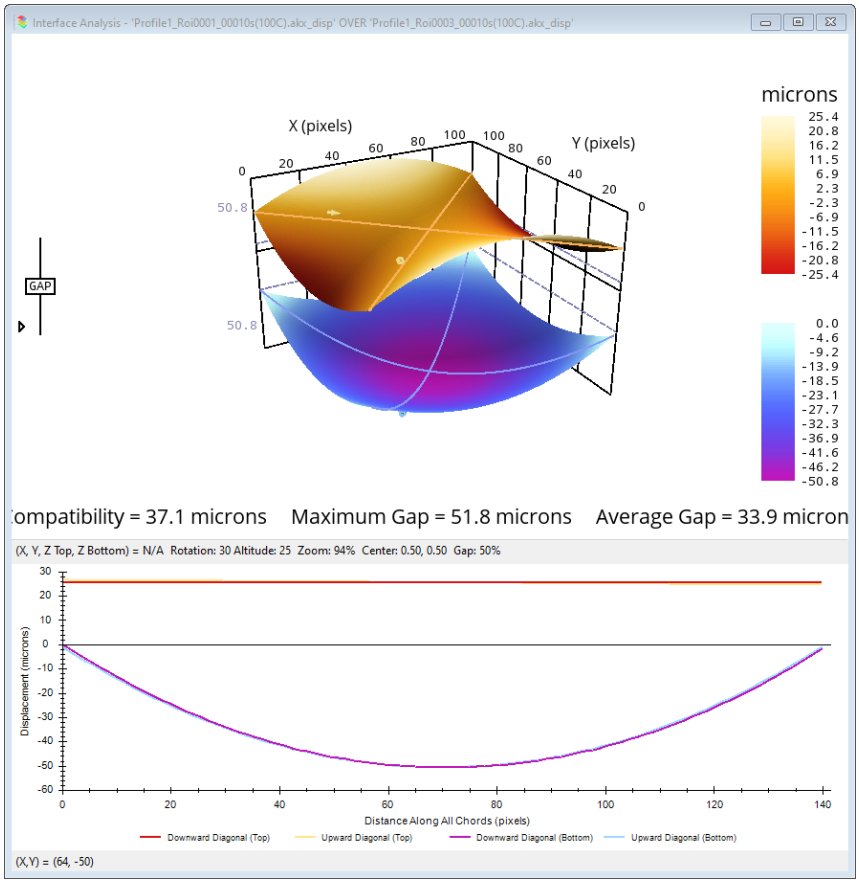


Figure 6.9 IA One-Off Result Window

Once a file has been chosen, a result window pops up as in **Figure 6.9**. A Gap slider on the left side of the 3D plot allows the two surfaces to be moved towards and away from each other. This does not affect the gauge calculations in any way but is only used for visualization purposes.

Alignment and rotation of the two surfaces is accomplished using the IA metadata fields, if present. If these metadata are not present, analysis will still proceed but no pin 1 rotation will occur and the file from which Interface Analysis was initiated will be the bottom surface. A note will appear indicating that IA metadata parameters have not been set (**Figure 6.10**).

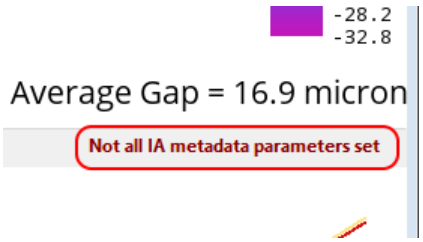


Figure 6.10 Not all IA metadata parameters set

IA 3D plots can be saved and settings altered via a right click context menu (**Figure 6.11**). The **File** menu allows the 3D plot to be saved. Under **Display**, the **Surface Mode** can be changed between **Top/Bottom** and **Gap** modes. Gap mode reduces the dual surface view down to just one showing the gap that exists between the two surfaces (**Figure 6.12**).

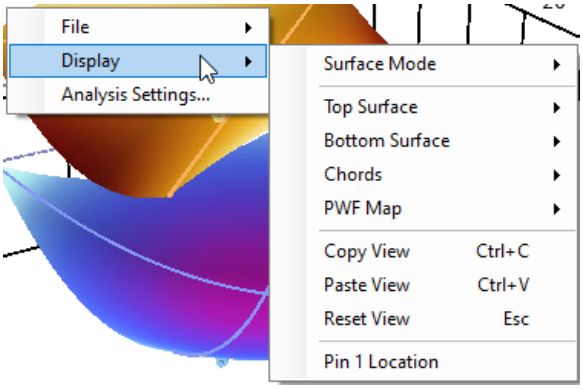


Figure 6.11 IA 3D Plot Context Menu

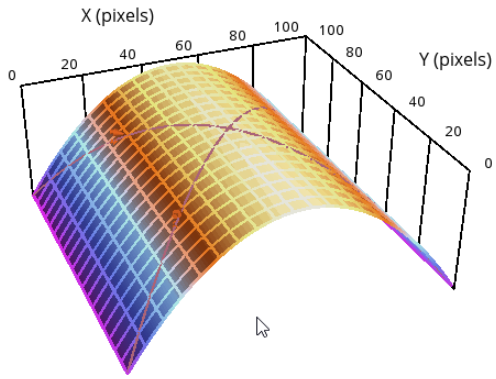


Figure 6.12 IA Gap mode plot

The top and bottom surfaces can be altered, shown, and hidden within the **Display** menu. Additionally, lines and arrows denoting the currently selected chord locations and directions can be shown/hidden under the **Chords** menu item. A pink colored dot locating the Pin 1 corner can be shown/hidden, and views can be copied/pasted between open 3D plots as well. Lastly, a PWF (pass/warning/fail) map can be enabled as either a third surface between the top and bottom surfaces (**Figure 6.13**) or overlaid on top of them (**Figure 6.14**).

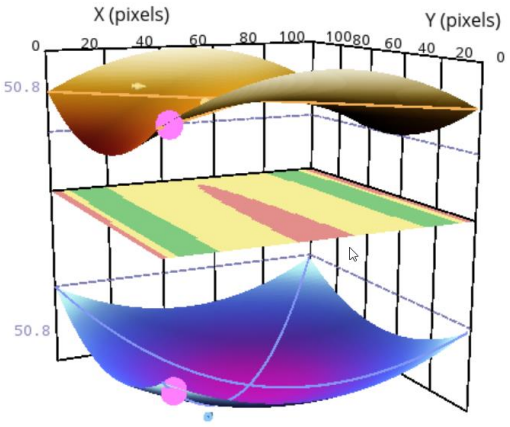


Figure 6.13 PWF map between Top and Bottom surfaces

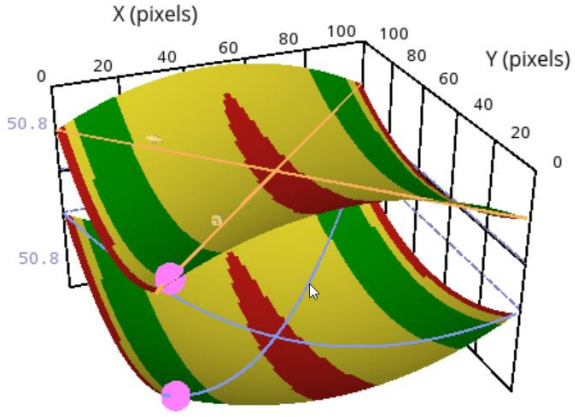


Figure 6.14 PWF map in overlay mode

The last main item in the context menu is Interface Analysis Settings (**Figure 6.15**). Here, physical dimensions can be added, and Z units changed between microns and mils. In addition, PWF limits can be assigned, and gauges chosen.

Note: PWF limit assignments are always in microns, regardless of Z Unit selection.

If the two surfaces' pixels dimensions are mismatched, the smaller surface is grown by default, but the opposite can be selected as well. Lastly, the Surface Offset Method (**Section 6.2**) can be chosen.

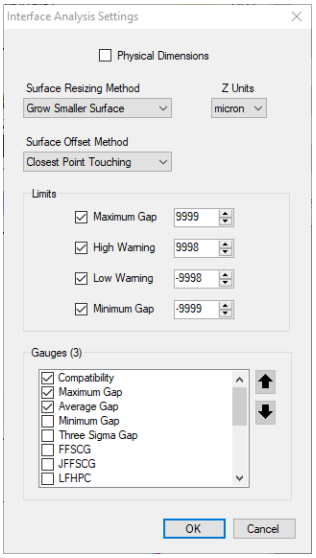


Figure 6.15 Interface Analysis Settings

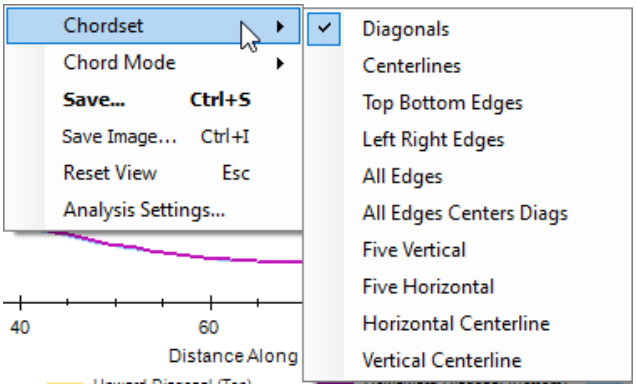


Figure 6.16 Interface Analysis Chord Context Menu

The chord section context menu (**Figure 6.16**) allows different chord groups and modes to be selected. In addition, the currently displayed chordset can be saved, either as a picture or data file.

6.4 Batch Interface Analysis

Found within the **Tools** menu, Batch Interface Analysis allows multiple pairs of files to be analyzed all at once. Multi-page reports can be created in similar ways to Batch Reporting (**Section 8**). Folders of displacement files (*.akx_disp) are added into a folder list via a right click context menu (**Figure 6.17**).

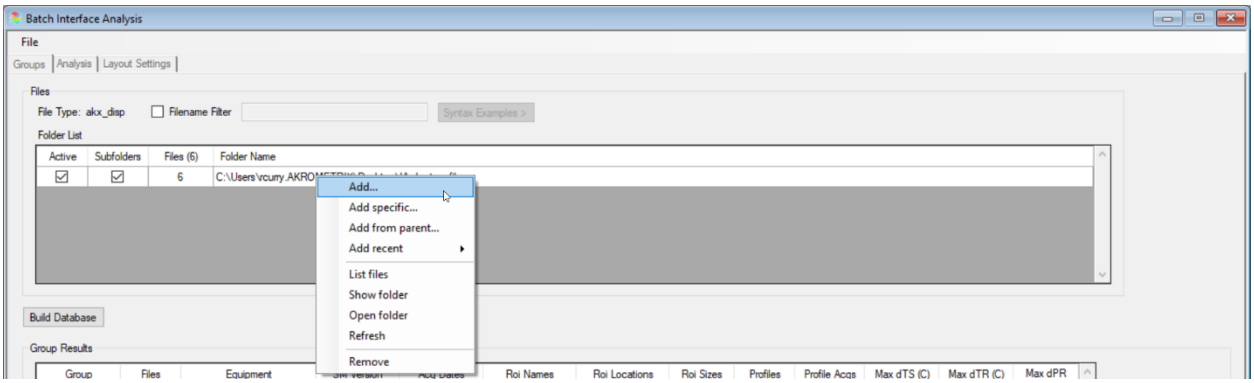


Figure 6.17 Batch Interface Analysis Add Folder Context Menu

Once a list of folders is added, a database is built of the file contents and Group Results are shown in two tables (**Figure 6.18**). The first table shows the state of the IA specific metadata for the input files in one of three categories, Bottoms, Tops, or Unspecified. Any displacement files that do not have all 3 IA metadata fields specified will be placed in the Unspecified category and will need to be updated to be included in the analysis. A right click context (**Figure 6.18**) menu allows metadata fields to be updated just as in Batch Reporting (**Section 8.1.4**).

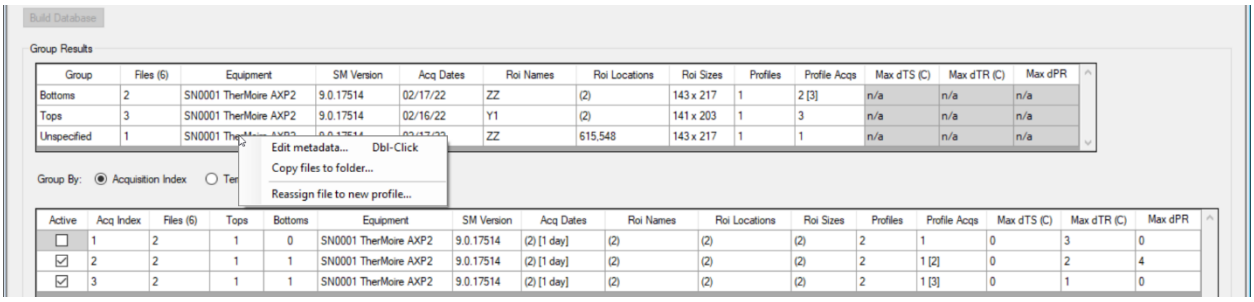


Figure 6.18 Batch Interface Analysis Group Results

Grouping of the input files can then take place either by the Acquisition Index or Temperature Nominal metadata fields. Once the group results are satisfactory, the Analysis tab can be selected to choose analysis options. Under Data Processing, there are two main options, All Individual Combinations, or Statistical Surfaces. All Individual Combinations analyzes every single possible pair of surfaces within each group. Statistical Surfaces combine tops and bottoms in a given group into single surfaces to compare. The different surface types and how they are calculated are described in **Section 6.4.1**. If Mix Combinations is chosen, different statistical surfaces can be calculated for bottom vs. top, although this is not typically used. In addition, there is an option to save these surfaces as displacement files to examine them as single surfaces.

Options below this are the same as available in one-off IA (**Section 6.3**). Once they are chosen, the Analyze button on the bottom left must be pressed to produce results. A preview of the results is shown to the right. Results for either Statistical Surface pairings or Individual Combinations can be shown by selecting the surface type from the drop-down box, typing in specific Top or Bottom surfaces indices, or clicking in the bottom table. A right click context menu is available on both 3D and Chord graphs with options that are largely similar to the context menu on a one-off IA result window (**Figure 6.11**). In addition, the chord graphs section can be hidden in this context menu (**Figure 6.19**).

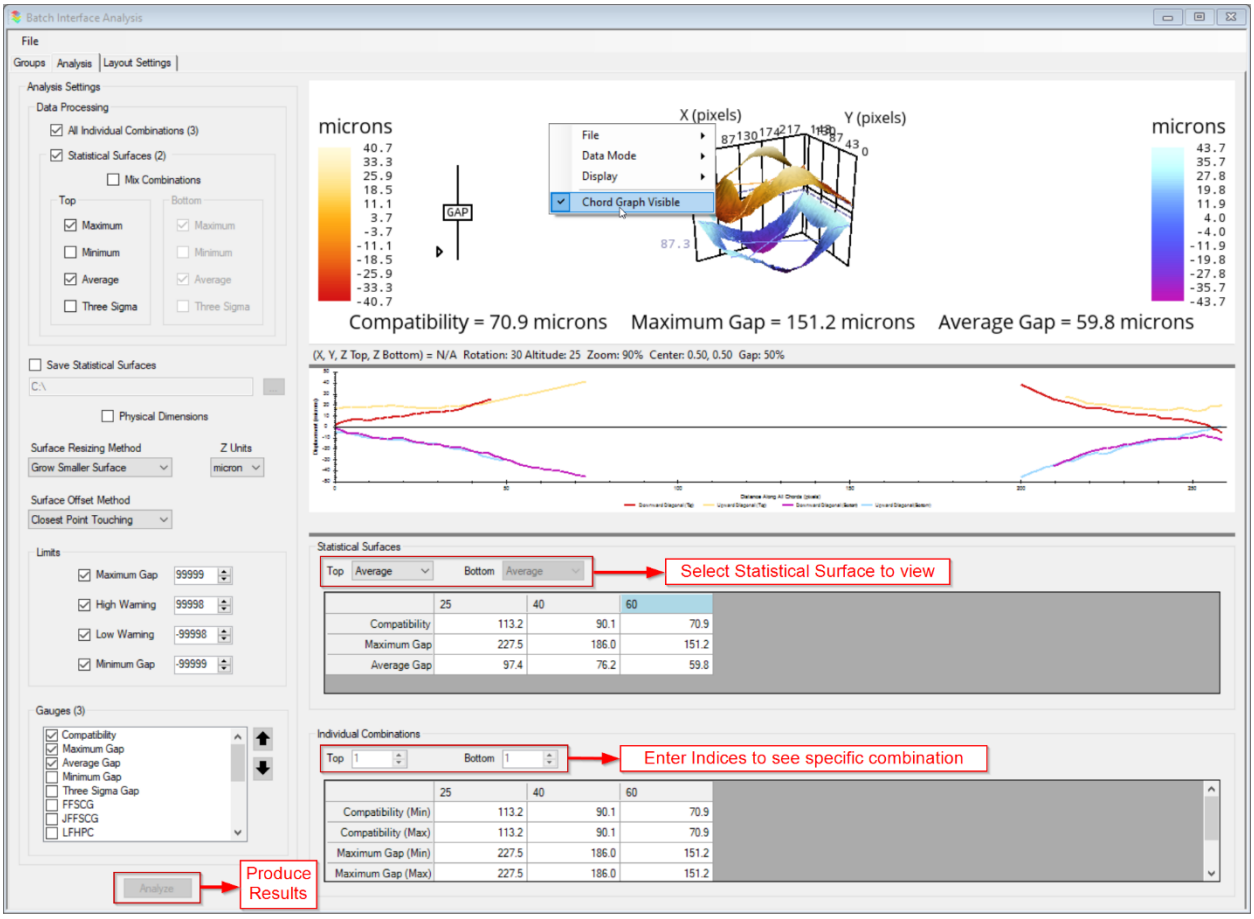


Figure 6.19 Batch IA Analysis Tab Results Preview

Once all the input data has been analyzed, the report layout can be configured on the Layout Settings tab (**Figure 6.20**). There are 3 main options available, depending on what was chosen during the analysis, Statistical Surfaces, Individual Pairings Gauge Extrema, and Individual Pairings. If those options are not analyzed, the corresponding section will be greyed out on the Layout Settings tab. Statistical Surfaces are discussed in **Section 6.4.1**. Individual Pairings shows all possible surface combinations. Individual Pairings Gauge Extrema shows specific pairs of data that exhibit the gauge extrema chosen. Options are Compatibility, Maximum Gap, or Average Gap. Page titles, subtitles, and image titles can all be entered using static text or metadata tags just as in Batch Reporting. Metadata tags are discussed further in **Section A.1.1**.

Below the 3 main surface options, are Data Graph options. These can be selected in either a Top/Bottom or Gap mode just as in One-off IA. Gauges can be added to graph footers using tags and Pin 1 indicator or image annotations added. A number next to the Data Graphs checkbox, in parentheses, indicates the total number of graphs that will be produced with the given Data Graphs selection.

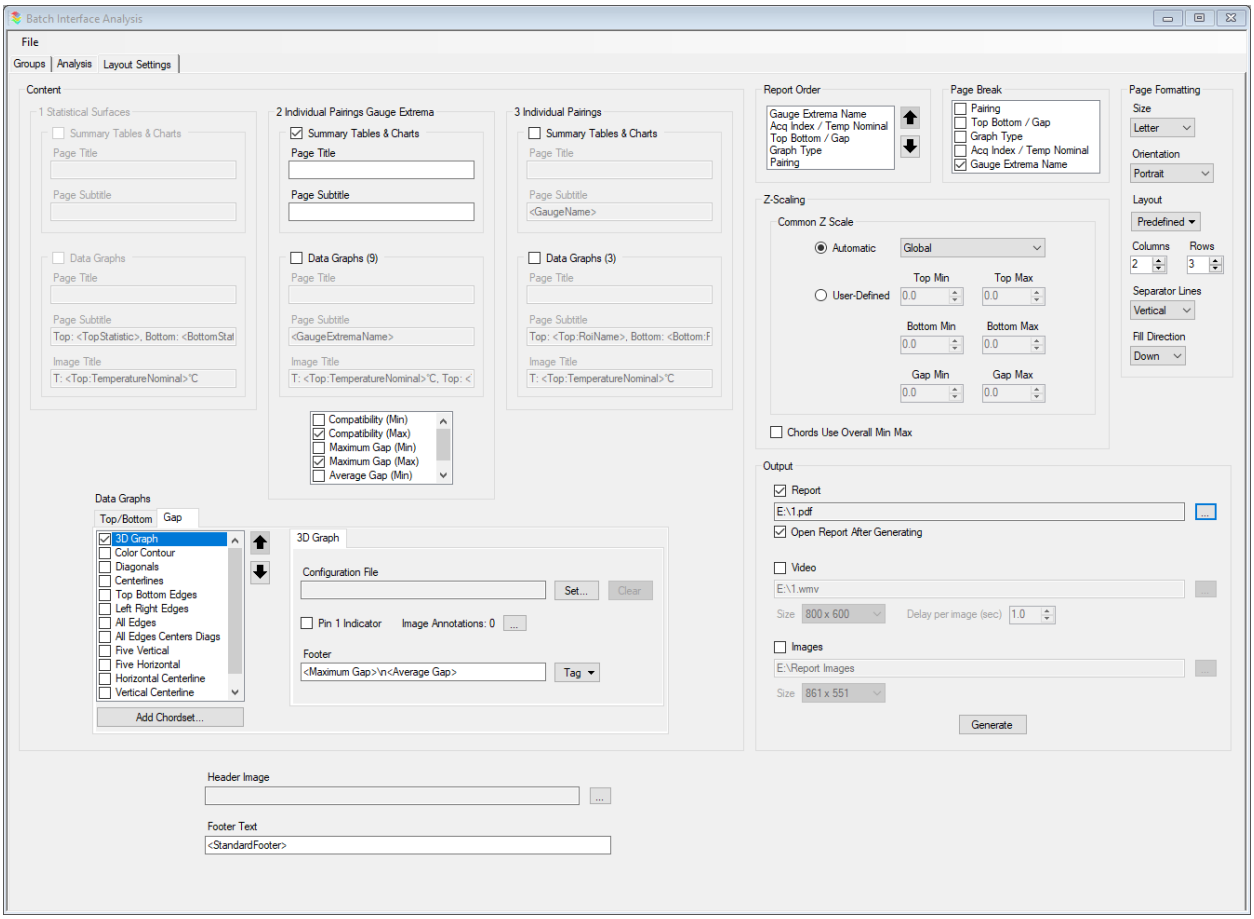


Figure 6.20 Batch IA Layout Settings Tab

Report Order and Page Break options follow to the right along with Page Formatting and Z-Scaling selection. Report Order chooses what variables or traits are prioritized first when building the report and Page Break options determine how and when new pages are created. Finally, outputs can be selected in either PDF, video, or image format. The selected outputs are created by pressing the Generate button.

6.4.1 Statistical Surfaces Output

One of the output options in Batch Interface Analysis examines the possible gaps between two surfaces using what are known as statistical surfaces. These surfaces are mathematical representations of the real surfaces that are input into the program. All the Top input surfaces are rotated to a least squares fit low 0 reference plane (see **Akrometrix Optical Techniques and Analyses 101** for a discussion of this fit plane) and all the Bottom surfaces are rotated to a LSF high 0 plane. Next, the following math operations are performed on the combined input surfaces at each pixel location in the surface matrix.

- **Maximum**

Top Surface: The maximum value is pulled from the top sample set at each pixel location and used to create the Top Maximum surface. This surface represents the maximum value away from the LSF low 0 plane at each pixel location in the input surfaces.

Bottom Surface: The maximum absolute value is pulled from the bottom sample set at each pixel location and used to create the Bottom Maximum surface. This surface represents the maximum value away from the LSF high 0 plane at each pixel location in the input surfaces.

- **Minimum**

Top Surface: The minimum value is pulled from the top sample set at each pixel location and used to create the Top Minimum surface. This surface represents the minimum value away from the LSF low 0 plane at each pixel location in the input surfaces.

Bottom Surface: The minimum absolute value is pulled from the bottom sample set at each pixel location and used to create the Bottom Minimum surface. This surface represents the minimum value away from the LSF high 0 plane at each pixel location in the input surfaces.

- **Average**

Top Surface: An average value is calculated at each pixel location and used to create the Average surface. This surface represents the average value away from the LSF low 0 plane at each pixel location in the input surfaces.

Bottom Surface: An average value is calculated at each pixel location and used to create the Average surface. This surface represents the average value away from the LSF high 0 plane at each pixel location in the input surfaces.

- **Three Sigma**

Top Surface: The standard deviation of Z values is calculated at each pixel location in the Top input surfaces. 3 times this standard deviation is added to the Average Top surface in order to create the Three Sigma Top surface. This surface represents the maximum normally distributed Z values away from the LSF low 0 plane at each pixel location in the Top input surfaces.

Bottom Surface: The standard deviation of Z values is calculated at each pixel location in the Bottom input surfaces. 3 times this standard deviation is then subtracted from the Average Bottom surface in order to create the Three Sigma Bottom surface. This surface represents the maximum normally distributed Z values away from the LSF high 0 plane at each pixel location in the Bottom input surfaces.

- **Example**

As an example, the following 4 perfectly spherical surfaces were input into Interface Analysis to show the resulting Statistical Surfaces. One concave, and one convex surface were the inputs for both top and bottom surfaces.

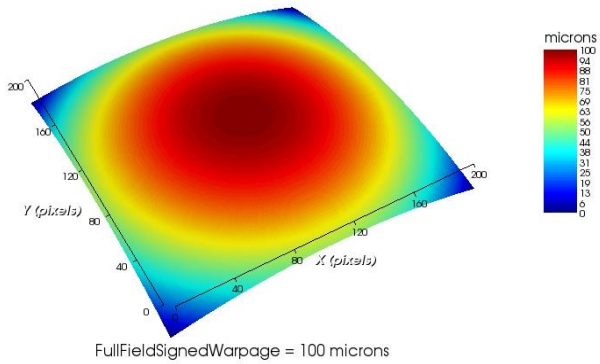


Figure 6.21 Convex LSF Low 0 Top

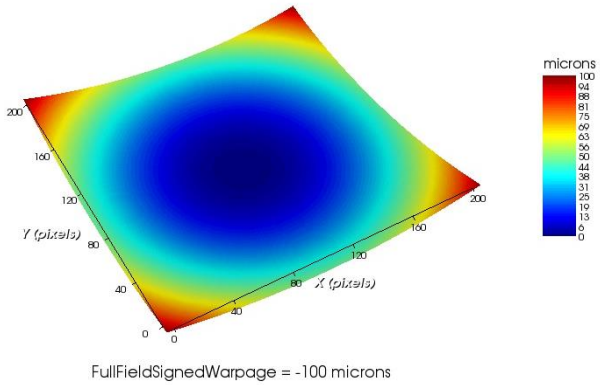


Figure 6.22 Concave LSF Low 0 Top

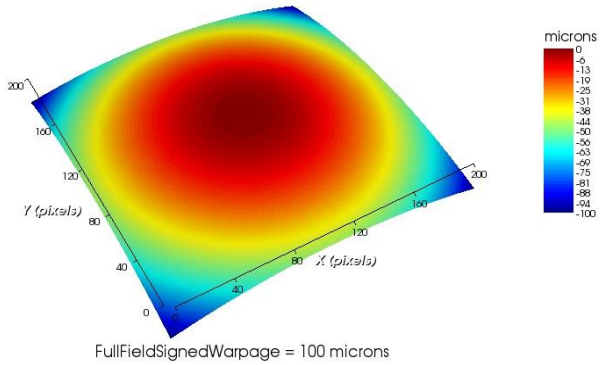


Figure 6.23 Convex LSF High 0 Bottom

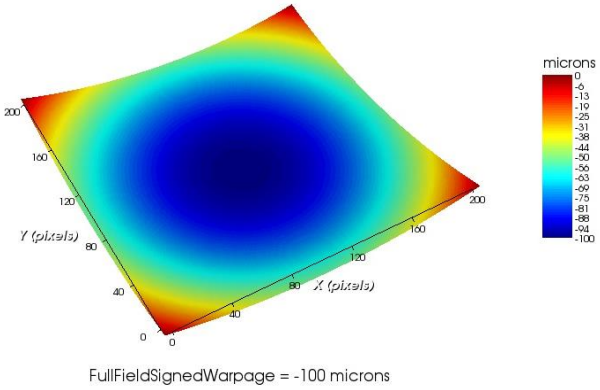


Figure 6.24 Concave LSF High 0 Bottom

The Top surfaces and Bottom surfaces are combined mathematically into the following composite Maximum surfaces. Notice how the curvatures are inverted depending on whether it is a Top Maximum or Bottom Maximum surface.

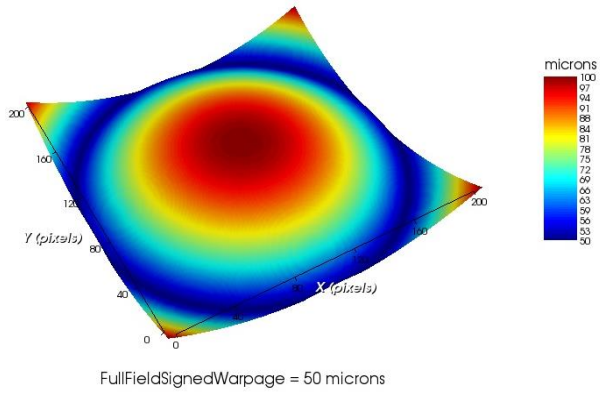


Figure 6.25 Top Maximum

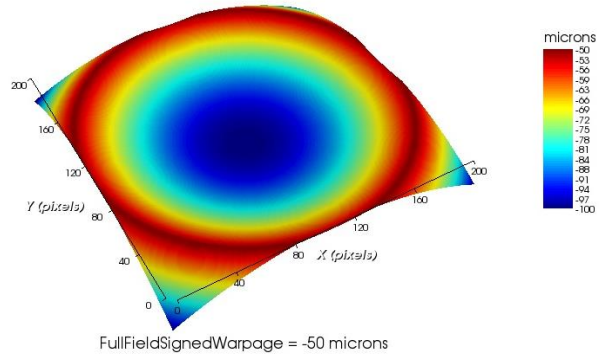


Figure 6.26 Bottom Maximum

Similarly, the following Minimum surfaces are produced:

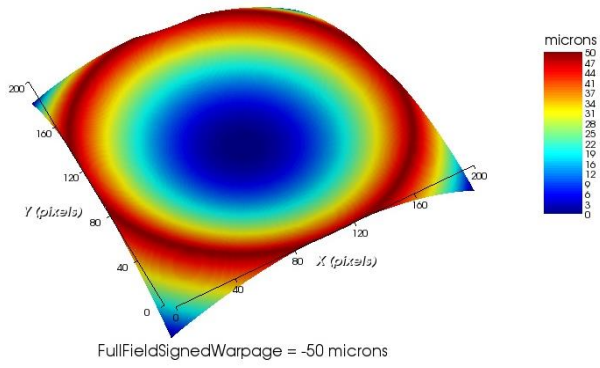


Figure 6.27 Top Minimum

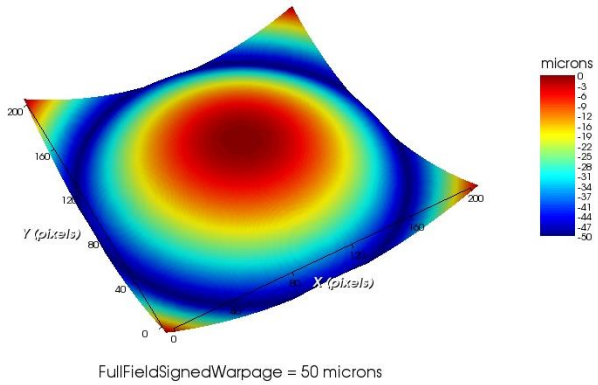


Figure 6.28 Bottom Minimum

The Average surfaces turn out to be completely flat in this example:

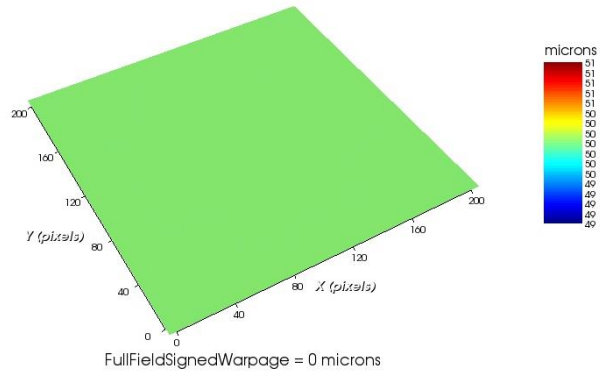


Figure 6.29 Top Average

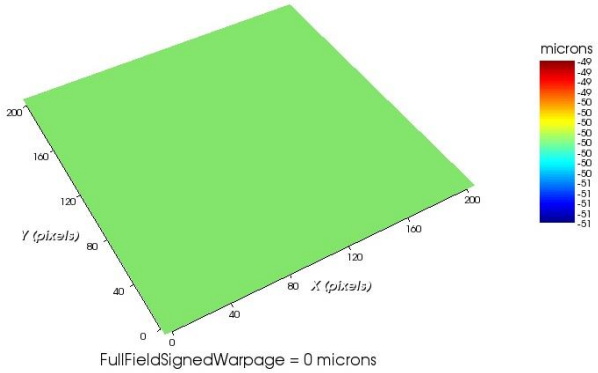


Figure 6.30 Bottom Average

Lastly, the Three Sigma surfaces are produced. If the gaps are normally distributed, these surfaces should account for more than 99% of the possible gap values.

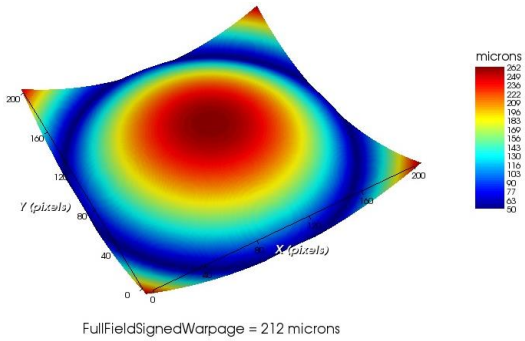


Figure 6.31 Top Three Sigma

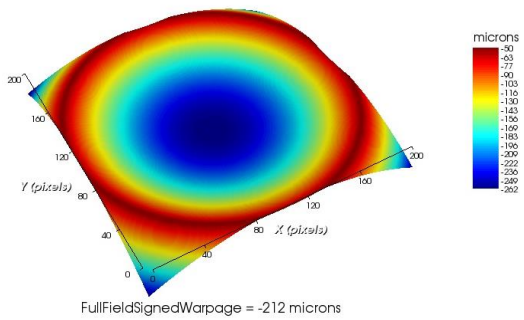


Figure 6.32 Bottom Three Sigma

6.5 Gauges

Please see the **Akrometrix Optical Techniques and Analyses 101** document for a complete discussion of Interface Analysis dual surface gauges.

7 Batch Processing

7.1 Batch Processing

Batch processing allows most of the one-off functionality in Surface Analysis to be performed on multiple data files with no user interaction. This functionality is very helpful when performing large experiments with multiple ROIs and/or multiple temperature points. There are six batch functions available:

- Batch Analyze
- Batch Mask
- Batch Rotate
- Batch Crop
- Batch Convert
- Feature Detection

To access the batch processing functions, select the **Tools→Batch Processing…** menu item. This will open a batch processing window (**Figure 7.1**). Tabbed screens appear for the six batch processing functions. Common menu items for these functions appear on a menu bar above the tabs.

Note: Multiple batch processing windows can be opened to process different data or process the same data with different settings.

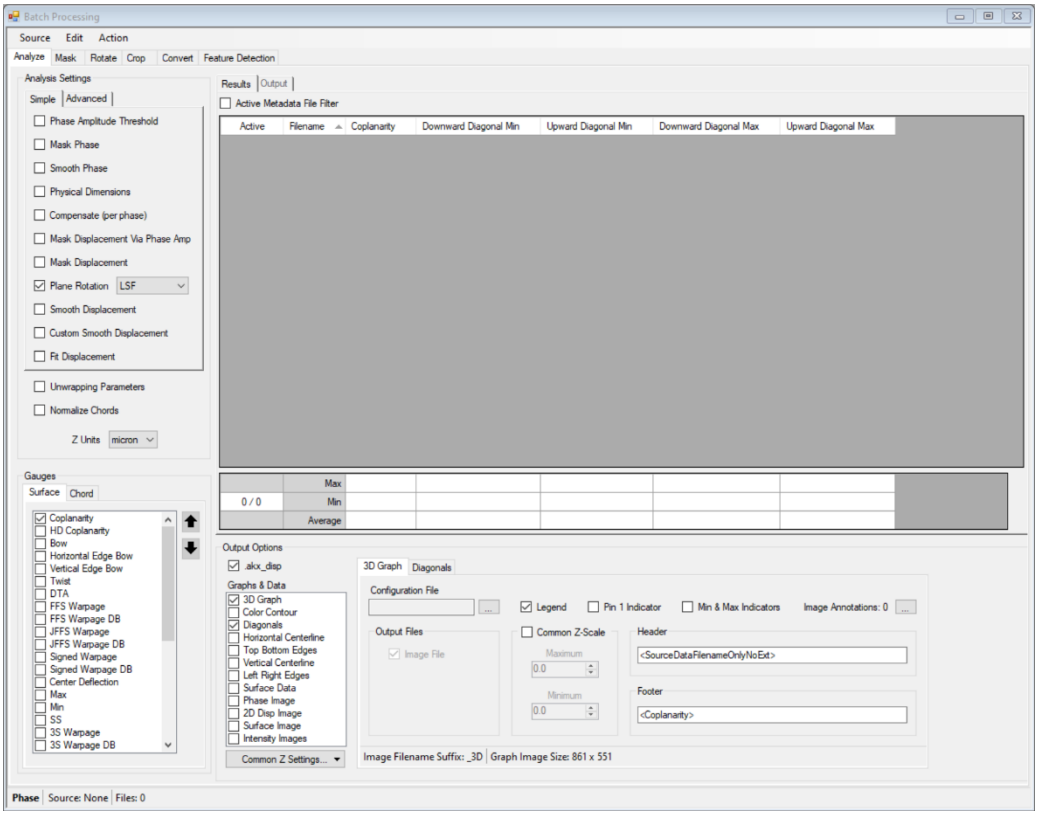


Figure 7.1 Batch Processing Screen

7.2 Batch Analysis

The batch analysis function opens the image or displacement files in the selected folder(s), analyzes the data, and saves the results in graphical and/or numerical format. This is useful, for example, for analyzing all the warpage measurements taken during a temperature profile and plotting the results on the same scale. The batch analysis tab window shows the conditions to be applied during analysis and display, while the action is initiated using the **Action** menu item.

Source → Select…	Identifies the folder of *.akx_phase or *.akx_disp files on which the batch processing functions will be applied. As of Studio 8.0, multiple folders can now be analyzed via a pop-up folder selector. See **Section 7.2.1**.
Edit → File Type	Switches between analyzing phase images (*.akx_phase) and displacement data (*.akx_disp).
Edit → Refresh Source Folder (F5)	Allows the user to update the file count since the folder was originally selected.
Edit → Settings → Load…	Loads settings for Batch Processing from a *.akx_recipe file
Edit → Settings → Save…	Saves settings for Batch Processing to a *.akx_recipe file
Edit → Settings → Load Defaults…	Loads program defaults
Edit → Settings → Set From Preferences	Loads settings from the Options window.
Edit → Settings → Duplicate Window	Opens a duplicate of the current batch processing window, including all loaded data and current settings.
Edit → 'Batch Results' Filename Template	This allows the user to set a template for the filename of the Batch Results file, which is automatically saved after analysis. The template must contain "Batch Results," and may also contain other strings and metadata tags. Metadata tags will use data from the first file in the table if applicable, and are available from the right-click context menu. Note that the file type cannot be changed from this dialog. **Tools→Options** (**Section 4.2**) is where this can be changed.
Edit → Output Performance →	Sequential or Parallel: for large batch operations parallel will speed up analysis at the expense of populating the table in non-sequential order.
Action → Analyze	Analyzes the phase or displacement files loaded into the file list.

Action → Generate Output	Produces output files (pictures and/or data) of various kinds and writes them to disk, as well as displaying images in the Output tab. See **Section 7.2.5**.
Action → Lock Results	Locks the results of analysis to a particular window. This option is not active unless Generate Output has been performed. While it is active, the output images will be held in temporary memory and will not be affected by any other analysis of the same files, allowing the user to compare different analysis settings on the same files. Unlocking the results will clear them from memory, requiring the files to be reanalyzed.
Action → Create Report…	Opens the report creation window with analysis data from the Current Batch pre-loaded in memory.

7.2.1 Using Batch Analysis

The key steps in using batch analysis are:

1. Select a folder to be analyzed (**Source→Select…** menu item). Multiple folders can be added by browsing for folders or by dragging and dropping from another window. Filenames can be filtered out by using the **Filename Filter** checkbox. Files can be added from a parent folder by right clicking on an already added folder row. Subfolders can be added via a checkbox on the folder row. If multiple rows are added, certain rows can be "deactivated" for quick comparison between multiple data sets without having to remove or add folders.

Note: A common filename filter that many users might find useful is to enclose some part of the filename in asterisks. For example, *PT* will only include files that include the string "PT" somewhere in the filename. This is particularly useful when filtering out part tracked search area files from the individual ROIs. PT can be substituted for any other string that's included in all the files needed.

Note: The List Files option in the context menu in **Figure 7.4** gives a list of all filenames of currently-active files in the folder. This can be used with Filename Filter to more precisely filter out any unwanted files.

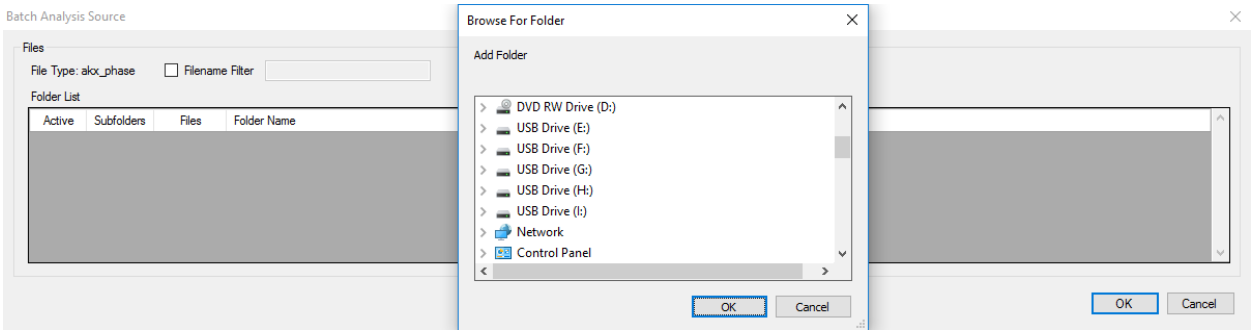


Figure 7.2 Batch Analysis Source Selection Browse for Folder

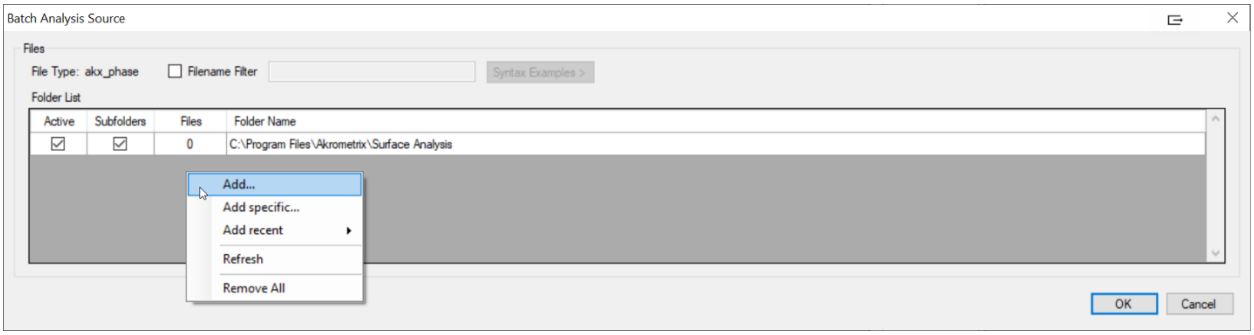


Figure 7.3 Batch Analysis Source Selection Add Folders

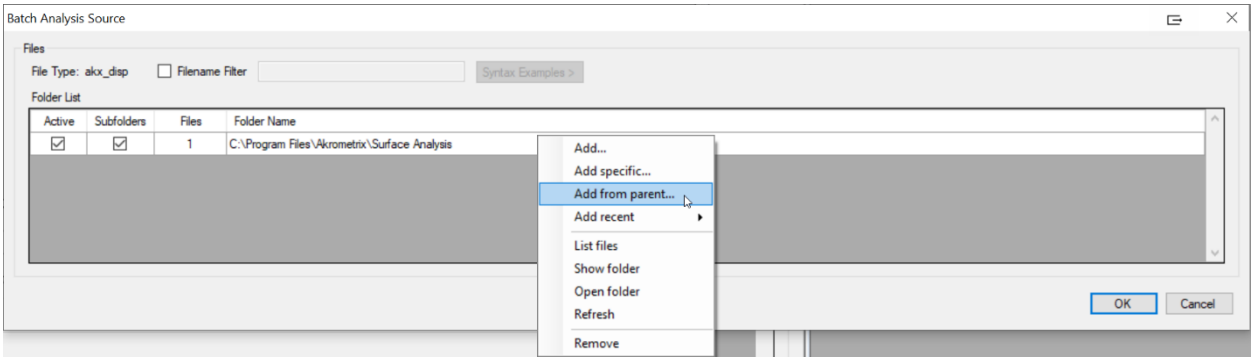


Figure 7.4 Batch Analysis Source Selection Add from parent...

2. Once all folders have been added to the Batch Analysis Source dialog, click OK. The files from this dialog will be populated into the Batch Analysis Results table sans any displacement gauge information. Right-clicking on a row brings up a context menu where individual files or folders can be opened. In addition, several options allow the user to set the active files en masse.

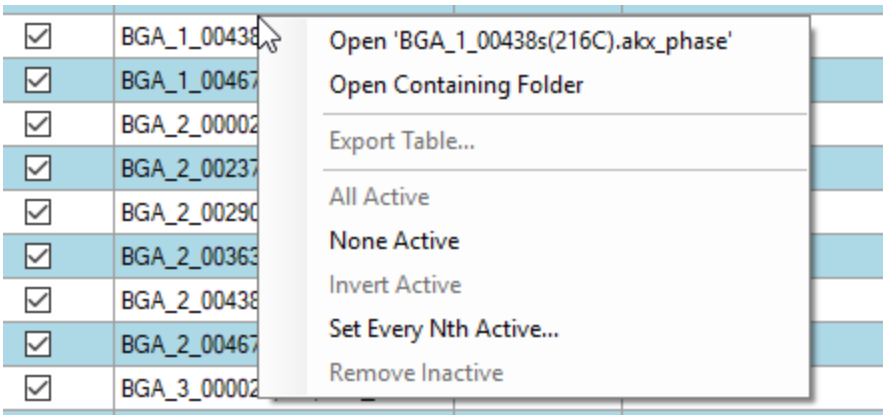


Figure 7.5 Analysis Results Table with Context Menu

3. Select analysis options (**Section 7.2.3**) and any additional columns of metadata required (right click on column headers in Results tab - **Figure 7.6** and **Figure 7.7**).

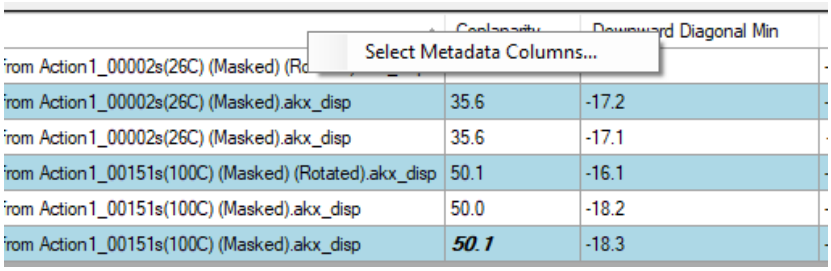


Figure 7.6 Batch Analysis Select Metadata Columns...

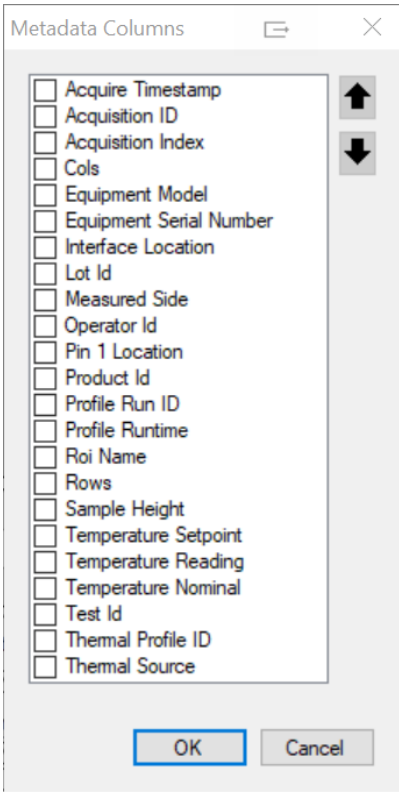


Figure 7.7 Batch Analysis Metadata Column Selector

4. Analyze the measurement data (**Action→Analyze** menu item). The measurement gauge results will be populated into the table. The extreme values of each parameter are shown below, which can provide the default scale for generating plots. The table is exported to each top level directory of the folders being analyzed.

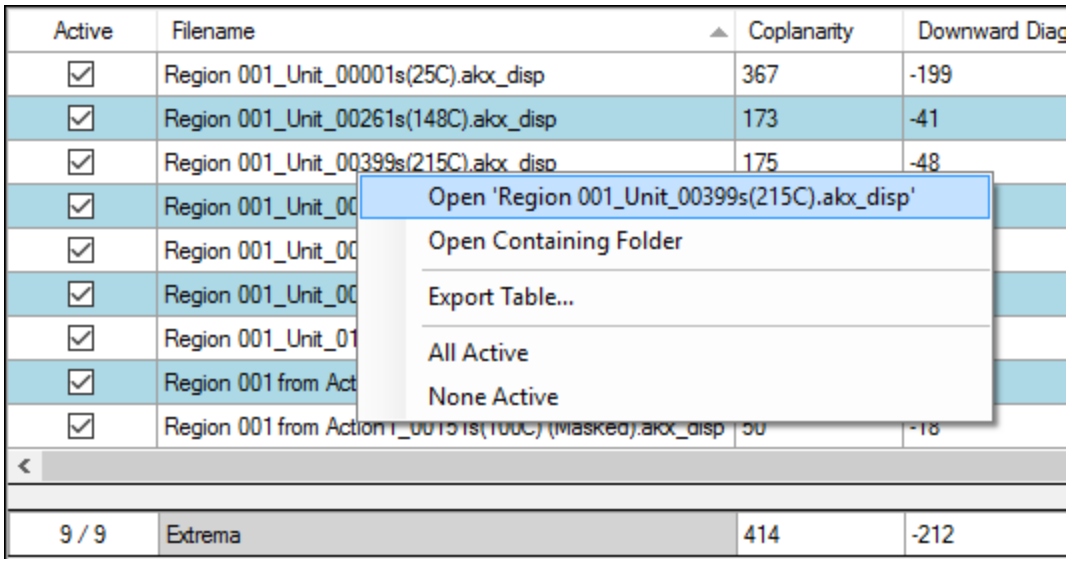


Figure 7.8 Batch Results Table after Analysis

5. Filter out any data not desired using the Active Metadata File Filter option. Files can be unchecked from being Active by setting up filter/logic conditions in the Metadata File Filter Query Builder (**Figure 7.9**). File filter queries can be saved and loaded as *.akx_query files in the Query Builder interface for future use.

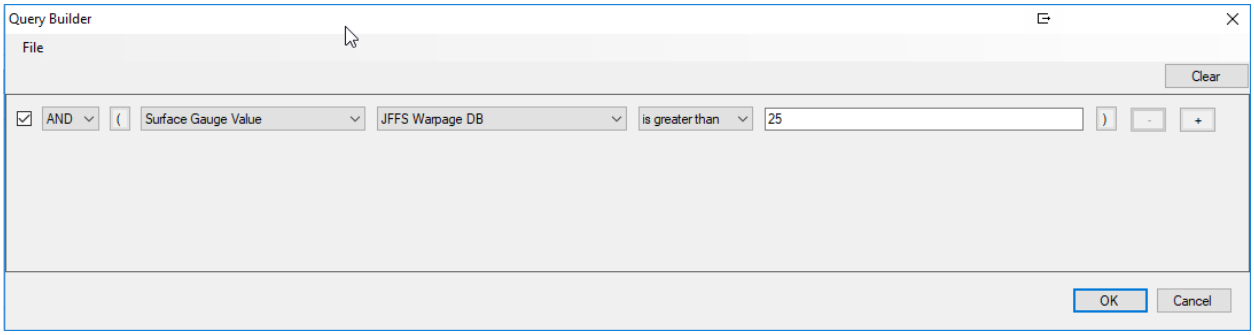


Figure 7.9 Metadata File Filter Query Builder

Note: All numerical queries occur in microns. The word “null” can be substituted for a numerical query to find results for gauges that have failed to calculate.

6. Select desired output and create results. The user may now either go to the automated report generator by selecting **Action→Create Report** (see **Section 8**) to create a formatted pdf report, or create and save images of the results using the **Action→Generate Output** functionality (see **Section 7.2.5**). Settings for the latter are found under Output Options (see **Section 7.2.4**).

7.2.2 Using Batch Analysis to Create Relative Plots

In order to set one of the images in the selected folder as a reference image (**Section 4.4**), double-click on one file in the summary table and confirm that all analysis should

use its 3D data as reference. The program will then save all graphs and numeric data as relative to this reference surface. All other steps remain the same.

7.2.3 Analysis Settings

Note: Phase operations listed below will not be available if the file type is set to *.akx_disp.

As of Studio 8.6, Analysis settings are grouped into a Simple and Advanced mode. Simple mode operates just as it did in previous versions, but Advanced gives the user additional flexibility in applying filters in different orders and multiple times.

Note: Many of the gauges listed below are abbreviated. Hovering over a given gauge with the mouse cursor will show a tooltip with the full name.

The base batch analysis filtering options are described below:

Phase Amplitude Threshold	Allows adjustment of the phase amplitude threshold on either an absolute or relative basis (see **Section 3.4**). A dialog appears with these options when checked.
Mask Phase	Applies a previously-created mask to phase images before analysis (see **Section 3.2**). A Load Mask window appears when the box is checked.
Smooth Phase	Applies a smoothing function once to phase images before analysis (see **Section 3.5.6**)
Physical Dimensions	Assigns a specific physical size to each data file (see **Section 2.3.5**).
Compensate (per phase)	Enables a compensation for the non-planar surface of the grating. Physical dimensions are required to perform this calculation
Mask Displacement Via Phase Amp	Allows adjustment of the phase amplitude threshold on either an absolute or relative basis (see **Section 2.4.10**). A dialog appears with these options when checked.
Mask Displacement	Applies a previously-created mask to displacement files before analysis (see **Section 3.2**). A Load Mask window appears when the box is checked.
Plane Rotation	Selects the reference plane rotation option to be used during analysis (see **Section 4.3**). Can be turned off to use the grating tilt as reference.
Smooth Displacement	Applies a smoothing function to the surface data. See **Optical Techniques and Analyses 101** for an explanation of this smoothing function.

Custom Smooth Displacement	Applies a custom smoothing function to the surface data. See **Optical Techniques and Analyses 101**.
Fit Displacement	Opens a dialog where a polynomial fit can be calculated based on the data set. See **Figure 5.2**. Alternatively, if physical dimensions are assigned to the phase image, a spherical fit can be calculated.
Unwrapping Parameters	Allows adjustment of the unwrapping parameters of each phase image for more accurate analysis. See **Section 4.6**.
Normalize Chords	Causes all chord plots to be displayed with the endpoints set to zero after analysis (see **Section 5.3.1**).
Z Units	Selects English or metric units for out-of-plane displacement results.
Gauges	Selects which gauges (numerical values quantifying flatness) are displayed at the bottom of the graphical display windows. A gauge on the list may be highlighted by clicking on it once. Checking a box means that gauge will be displayed. The up and down arrows move the highlighted gauge up and down the list, changing the order in which gauges are displayed. Gauges are defined in the **Optical Techniques and Analyses 101** manual. The ROC, DTA, Bow, and Twist gauges all require physical dimensions to be applied to the phase image. Step height definition files (*.akx_StepDef) can also be loaded and calculated alongside normal gauges, as can custom chordsets (*.akx_chordset).

In the Advanced mode, filters can be adding by using the right click context menu. A 'Set All from Simple' option allows for the Advanced mode to be set to mimic the behavior of options currently set in the Simple mode. Additionally, filters can be added in this context menu, and settings altered for certain filters. Arrows on the right hand side allow filters to be re-ordered.

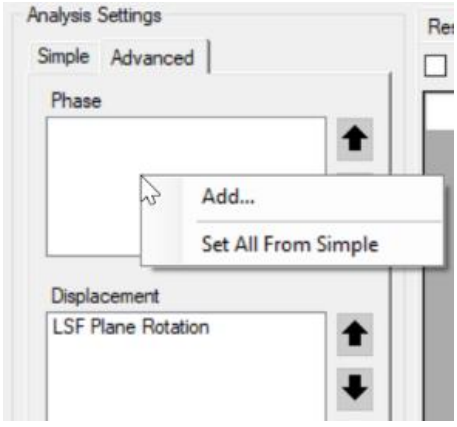


Figure 7.10. Analysis Settings Advanced Mode

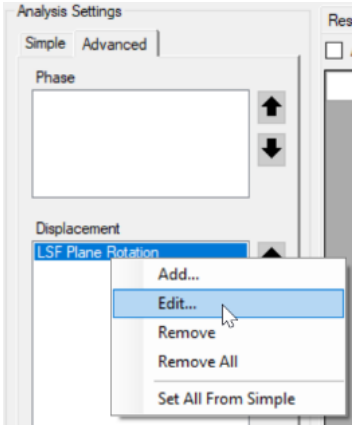


Figure 7.11. Analysis Settings Advanced Mode Edit Filter

7.2.4 Output Options

These options affect the results of the **Action→Generate Output** command (See **Section 7.2.5**).

.akx_disp Saves *.akx_disp files to disk during analysis. These files are produced in memory during analysis anyways, so this saves time and an extra step if the user knows that they want them anyways. When displacement files are the input, *_mod.akx_disp files are saved to denote the modified displacement files.

Graphs & Data Selects which graph/data/image formats (see **Sections 5.1** through **5.4**) are saved during **Generate Output**.

Configuration File Allows the user to load a non-default display format for saved graphs. The 3D configuration file has an extension of *.akx_3Dconfig and is used for 3D plots (3D and Contour). See **Section 5.1**. The 2D configuration file has an extension of *.akx_2Dconfig file and is used for 2D Chord plots. See **Section 5.3**.

Legend Selects if a legend is displayed on each graph.

Pin 1 Indicator Places a pink sphere on the 3D or Color Contour plot types in the pin 1 corner of the data set.

Min & Max Indicators Displays blue and red spheres where the min and max Z values are on the 3D Graph or Color Contour plots.

Image Annotations: Allows arbitrary graphics to be placed on 3D Graph and Color Contour plots. Right click to bring up Add Image… context menu. Aspect Ratio, Size, Location, and X/Y Offset can be controlled to position the image in the desired location.

Figure 7.12 Image Annotations List

Common Z-Scale When checked, causes all 3D or 2D plots generated by batch analysis to use the same vertical scale. Default min and max values are determined by the extremes in the combined data sets, but may be edited using the text box. When unchecked, each image is plotted on a scale set by its own data set.

Common Z Settings… The Auto update switch chooses whether to change the Common Z-Scale after each analysis. The Chords use overall Min Max switch puts the same Z-Scale into the chord plots as the 3Ds. If the user has analyzed something but changed the default Z-Scale value based upon the current file list, the Update button will restore the default Z-Scale.

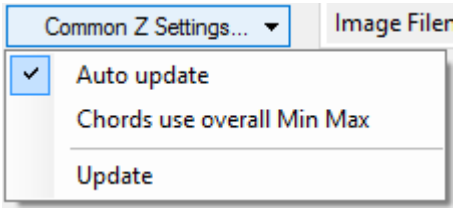


Figure 7.13 Common Z Settings

Output Files This section is only active on chord plot tabs. Chord tabs allow the user to select whether images, data, or both are output.

Header The header for each image file can be created using tags from the metadata stored in each input phase or displacement file. Available tags can be found in the properties of a phase or displacement image. Tags will reference the original file metadata such that the entry is a variable changing on input file. The default <SourceDataFilenameOnlyNoExt> tag puts the file name minus its extension into the header. The user can also enter any normal text as a constant header.

Footer Allows the user to choose the footer from the available gauges chosen during analysis. Each gauge is input using brackets and the name as spelled in the Analysis Options Gauges section. For example, <Coplanarity> will add the Coplanarity gauge to the bottom of the graph. “\t” inserts a tab character and “\n” inserts a return character to start a new line.

Graph Image Size Displays the image size to be output (will vary if config file is loaded with different image size).

After output is generated, image and data files are saved to the folder in which the original phase or displacement file is located.

Note: PNG files are the only option for output graphs as of Studio 8.0.

Options for the Surface Data, Phase Image, and 2D Disp Image can be selected by right-clicking on the respective data type. These options are explained below.

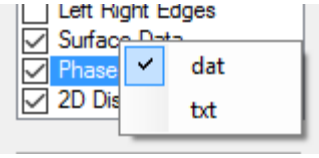


Figure 7.14 Surface Data Options

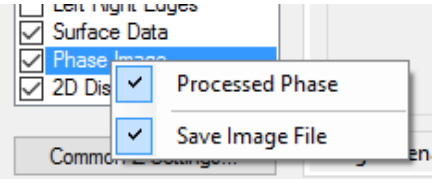


Figure 7.15 Phase Image Options

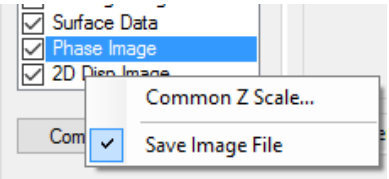


Figure 7.16 2D Disp Image Options

Surface data files can be exported as either *.dat, or *.txt, for importing into other numerical analysis programs. Phase Image files can be saved to disk or not in either the processed form (phase smooth is the only option that would change the phase data) or raw form. Lastly, 2D Disp Images can be saved to disk or not with either a common Z-scale across all pictures or individual Z-scales on each picture.

7.2.5 Output Tab

After analyzing the data, the user may save images and directly view their results by selecting **Action→Generate Output**. This brings up an Output tab in which all plots selected under Output Options are visible. The user can use the arrows and tabs here to switch between files and graph types. If the results are locked using **Action→Lock Results**, then the images will remain visible even if the underlying *.akx_disp files are altered or overwritten.

If the user has opened multiple batch processing windows, then it is possible to sync the visible image between them, allowing for side-by-side comparison of different analysis options. This is done using the context menu shown in **Figure 7.17**. The sync option is not available in a given batch processing tab unless its results are locked. When selected, the result plot is changed on all batch processing windows currently open when it is changed on one. This allows for quick comparison of results between different batch processing windows.

Note: All batch processing results windows must be locked for the Sync option to be available.

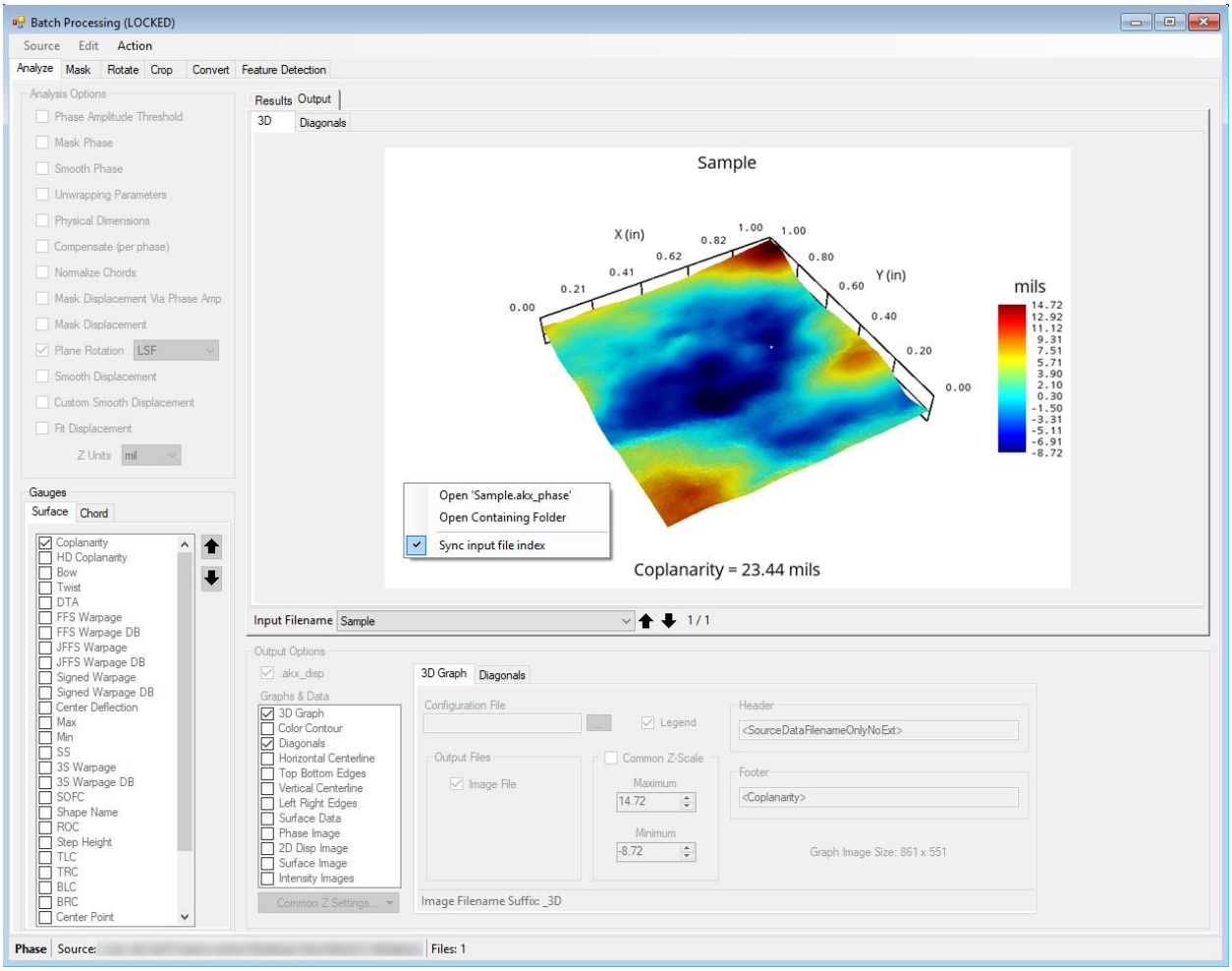


Figure 7.17 Output Tab

7.3 Batch Masking

The Batch Mask feature allows the user to automate mask-burning for multiple image files contained in a specified folder (**Figure 7.18**).

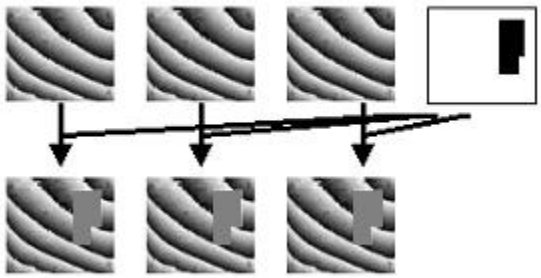


Figure 7.18 Batch Burn

7.3.1 Using Batch Masking

As of Studio 9.0, there are four distinct forms of masking available in the *.akx_phase Batch Mask tab: Phase Amplitude, Layout Mask, Expand Mask Points, and Mask Data

Islands. These options can be used independently or together by selecting the various checkboxes.

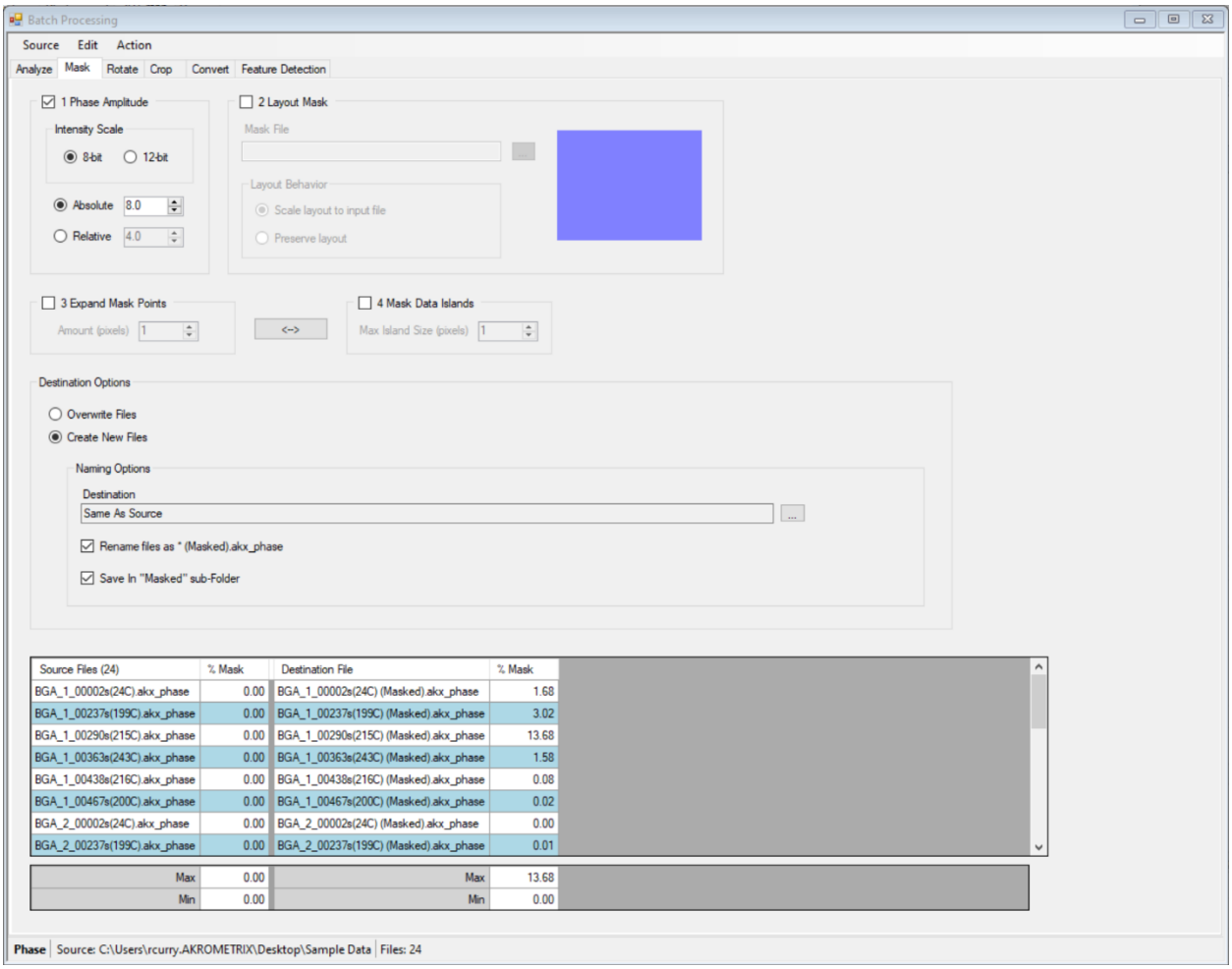


Figure 7.19 Batch Masking Screen

Layout Mask is the original region mask function. It uses a mask file, as described in **Section 3.2**. The mask file must be created and saved prior to the batch masking operation.

The key steps in masking are:

1. Select a folder containing data files to be masked (**Source→Select…** menu item)
2. Check the boxes for all types of masking that will be applied.
3. If using Phase Amplitude, check the correct Intensity Scale for the input files and the desired Absolute or Relative Threshold. (see **Section 3.4** for background)
4. If using Layout Mask, select a mask file (see **Section 3.2** to create and save masks) to be applied, then select the Layout behavior.
5. If using Expand Mask Points or Mask Data Islands, enter pixel counts (see **Sections 3.2.6** and **3.2.7)**.

6. If using both, choose the order in which Expand Mask Points and Mask Data Islands occur (see **Section 7.3.7**).
7. Select destination options (**Section 7.3.8**)
8. Create and save results (**Action→Mask** menu item)

7.3.2 Source, Edit, and Action Menus

Source → Select…	Identifies the folder of *.akx_phase or *.akx_disp files on which the mask will be applied.
Source → Recent	Shows the 4 most recent folders that were used.
Edit → File Type	Switches between masking phase images (*.akx_phase) and displacement data (*.akx_disp). When masking *.akx_disp files, new options become available (see **Section 7.3.9**).
Edit → Include Subfolders	Applies the batch processing function to subfolders within the selected folder in addition to the original folder.
Edit → Refresh Source Folder (F5)	Allows the user to update the file count since the folder was originally selected.
Action → Mask	Performs the mask operation

7.3.3 Loading a Mask File

Mask File Click on button on the right to browse for a mask file.

7.3.4 Layout Behavior

Choose whether to scale the input mask file if any difference in dimension exists or to preserve the layout. If preserve is chosen and the array dimensions do not match, the mask array will be anchored to the top left of each image and any mask regions which lie outside the image dimensions will be truncated.

7.3.5 Expand Mask Points

Choose how many pixels to expand the mask by. This function takes place after Layout Mask. It will extend any masked areas that were already in the image, plus the regions from layout mask, if applicable. See **Section 3.2.6** for details on expanding mask points.

7.3.6 Mask Data Islands

Choose how many pixels the largest masked data island should have. Any disconnected islands in the data of that size or smaller will be removed. Like Expand Mask Points, it will remove both islands that were already present in the data and any created by the application of Layout Mask.

7.3.7 Changing Masking Order

By default, Expand Mask Points happens before Mask Data Islands, but this order can be changed by clicking the **<->** button between them. If Expand Mask Points is

applied first, then the edges of the mask will push closer and there will likely be more data islands small enough to be removed. If data islands are removed first, then any small regions of data created by expanding the mask will remain.

7.3.8 Destination and Naming Options

Overwrite Files	Causes masked files to overwrite original data files.
Create New Files	Saves masked images to a new destination and/or with a new name. The original data files are unchanged.
Destination	Selects the folder to which the masked images will be saved. Click on the ... button to the right to browse for the destination folder.
Rename files as *(Masked).akx_phase (disp)	Appends the string "(Masked)" to the end of the original filename for the masked file.
Save In "Masked" sub-Folder	A single new folder named "Masked" will be created in the destination folder and all masked files will be saved in this subfolder.

7.3.9 Mask Results Table

A Results section appears at the bottom of the interface. This table populates with a list of the source filenames when files are loaded. The rest of the table does not populate until masking has been performed. Once it has, the table fills with percentage masked information, plus overall minima and maxima when working with displacement files. The resulting information is useful as feedback for whether the given mask operations were successful.

7.3.10 Masking Displacement Files

When masking *.akx_disp files in Batch Mask, several new options appear in the Batch Processing Window, as shown in **Figure 7.20**. These options are Z-Range Mask and Plane Rotation.

Displacement files can be masked with the standard mask operations described earlier, Z-Range Masks, or some combination thereof. Z-Range Mask functionality is described in **Section 2.4.8**, and works with the same options in batch mode as in one-off. In Absolute or Percent modes, a range and mask logic are set to mask the source files, or a *.akx_zRangeMask file is loaded containing these settings. To enter Region mode, a *.akx_zRangeMask file must be loaded containing at least one region. The metric, logic, and offset can then be adjusted just as in one-off mode before masking.

Plane Rotation allows the masked data rotation to be adjusted. The rotation options are those described in **Section 4.3**. This is useful for masking out noisy data that might have adversely affected initial rotation.

The order of the different masking operations is indicated by the numbers before each operation name and should be kept in mind when using several different operations.

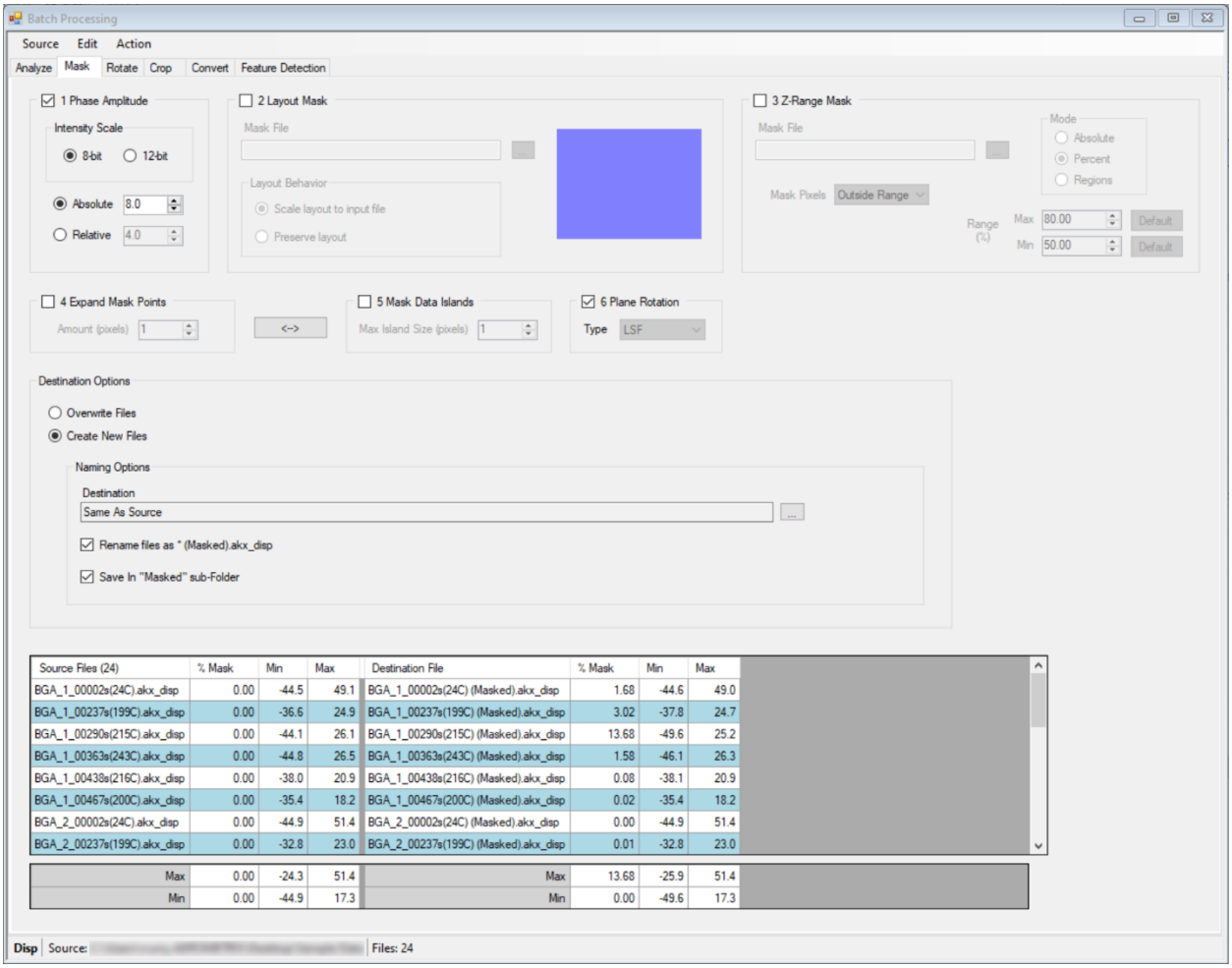


Figure 7.20 Batch Mask Results for Displacement Files

7.4 Batch Rotation

7.4.1 Using Batch Rotation

Phase image rotation is described in **Section 3.7** and also applies to displacement files. This batch function rotates all the images in the selected folder according to the options set in the batch rotation tab window. The batch rotation screen is shown in **Figure 7.21**.

Figure 7.21 Batch Rotation Screen

The key steps in using batch rotation are:

1. Select a folder containing images to be rotated (**Source→Select…** menu item)
2. Select rotation options (see **Section 7.4.2**)
3. Select destination options (see **Section 7.4.3**)
4. Create and save results (**Action→Rotate** menu item)

The Source, Edit, and Action menus for Rotation are all virtually identical to the Mask operation.

7.4.2 Rotation Options

Angle	Enter number of degrees to rotate the image clockwise or counterclockwise.

7.4.3 Destination and Naming Options

Overwrite Files	Causes rotated data to overwrite original data files.
Create New Files	Saves rotated data to a new destination and/or with a new name. The original data files are unchanged.
Destination	Selects the folder to which the rotated data will be saved. Click on the ... button to the right to browse for the destination folder.
Rename files as *(Rotated).akx_phase (disp)	Appends the string “(Rotated)” to the end of the original filename for the rotated file.
Save In “Rotated” sub-Folder	A single new folder named “Rotated” will be created in the destination folder and all rotated files will be saved in this subfolder.

7.5 Batch Cropping

Batch cropping allows the user to extract multiple regions of interest from multiple phase or displacement images. For example, a measurement test which produces measurement data at three temperature points, with each phase or displacement image containing four regions of interest (3 × 4 = 12 measurements), can be easily analyzed in a two-step procedure: batch cropping, followed by batch analysis (**Figure 7.22**).

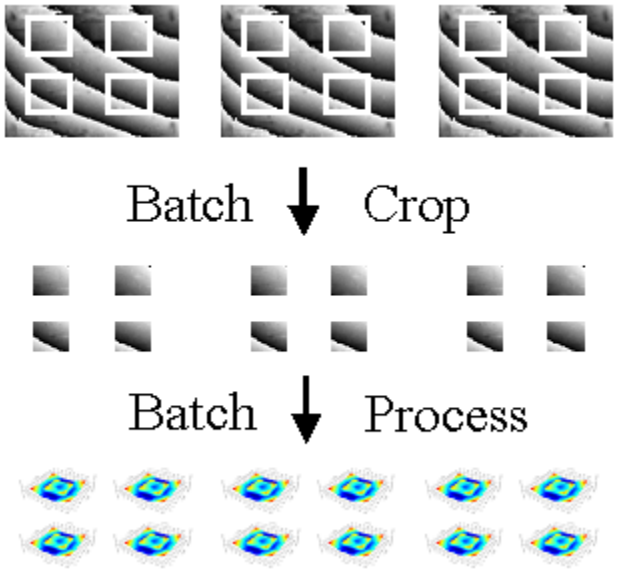


Figure 7.22 Batch Cropping and Analysis

As of Studio 8.5, there are two methods of cropping a file available on the Batch Crop tab: Crop To Extents and Partition.

Crop To Extents removes masked data (white space) from the edges of images and does not require a partition. This is most useful after analysis that involved removing data from the edges of an image via masking. See **Section 3.5.6** for a graphical illustration of how Crop To Extents works.

7.5.1 Using Batch Cropping

The cropping mode can be changed by using the radio buttons at the top of the batch crop tab.

Crop to Extents does not require a partition but otherwise uses the same process as partition cropping, including the creation of new, cropped files.

Partition cropping requires that the user has created a partition file as described in **Section 3.5**. This must be created and saved prior to the batch cropping operation. The partition may contain one or more ROIs. All the ROIs from each image in the selected

folder are saved as new, independent files, organized and named using the Destination Options on the batch crop tab.

If Partition mode is selected, the user must also choose a partition file and layout behavior (see **Section 7.5.2**) To choose a partition, click on the ... button and browse for it. A preview of the partition file will show on the right.

The resulting image files can be batch processed in a second step to complete the analysis. The batch cropping screen is shown in **Figure 7.23**.

The key steps in using batch cropping are:

1. Select a folder containing images to be cropped (**Source→Select**… menu item)
2. Either select a partition (see **Section 3.5** to create and save partitions) to be applied, or choose Crop To Extents.
3. Select destination options (**Section 7.5.3**)
4. Create and save results (**Action→Crop** menu item)

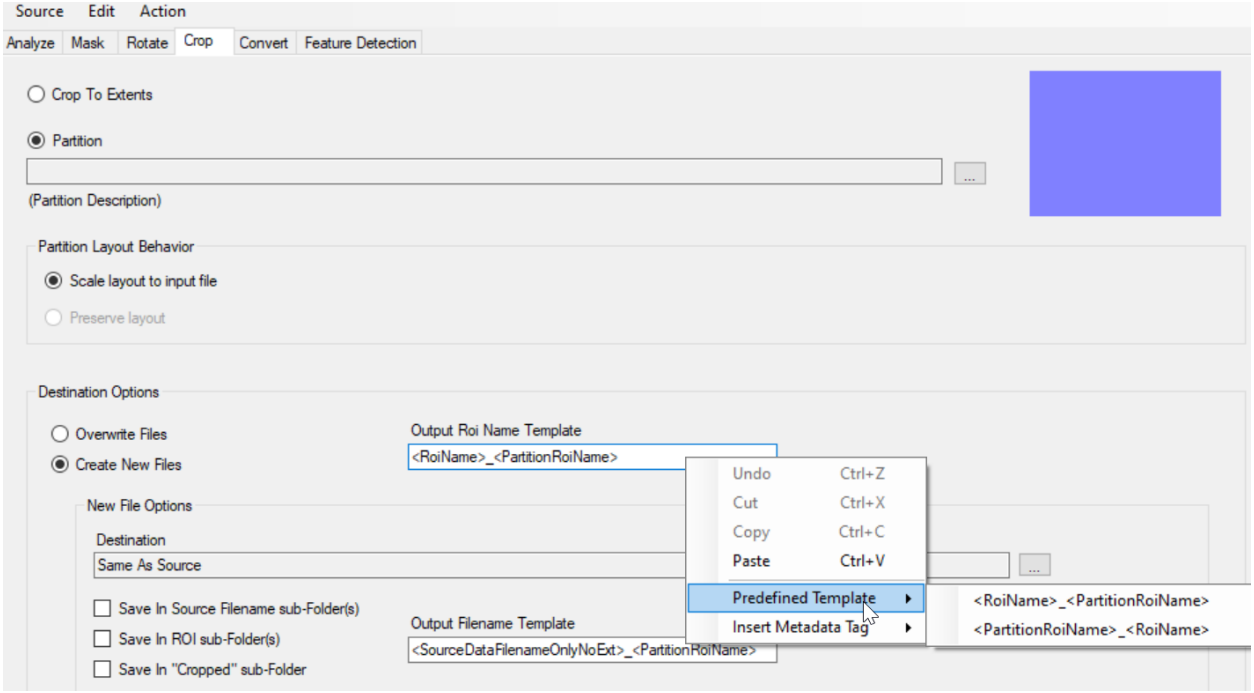


Figure 7.23 Batch Cropping Screen

7.5.2 Partition Layout Behavior

In Partition mode, the Layout Behavior must be selected. Choose whether to scale the input partition file if any difference in dimension exists or to preserve the layout. If preserve is chosen and the array dimensions do not match, the partition array will be anchored to the top left of each image and any regions which lie outside the image dimensions will be truncated.

7.5.3 Destination and Naming Options

Because **Crop To Extents** does not use a partition file, some of these options are absent or greyed out in that mode.

Overwrite Files	Causes cropped files to overwrite original data files. This should not be used for partition crop with multiple domains.
Create New Files	Saves cropped images to a new destination with a new name. The original data files are unchanged.
Output Roi Name Template	Allows the user to create a template for ROI names of the output files. This template must contain the <PartitionRoiName> metadata tag. It may also contain other metadata tags or strings. Preset templates and common metadata tags are accessible through the right-click context menu.
Destination	Selects the folder to which the cropped images will be saved. Click on the button to the right to browse for the destination folder.
Save in Source Filename sub-Folders	A new folder will be created for each file in the source folder and all cropped images derived from each file will be collected in this subfolder.
Save in ROI sub-Folder(s)	A new folder will be created for each ROI in the partition and all cropped data derived from this ROI for all files will be collected in this subfolder.
Save In "Cropped" sub-Folder	A single new folder named "Cropped" will be created in the destination folder and all cropped files will be collected in this subfolder.
Output Filename Template	Allows the user to create a template for the filenames of the output files. To avoid overwriting, this template must contain the <SourceDataFilenameOnlyNoExt> tag, as well as <PartitionRoiName> in Partition mode. It may also contain other metadata tags or strings. Preset templates and common metadata tags are accessible through the right-click context menu.

7.6 Batch Edit XY Orientation

This functionality has been moved to the more powerful metadata editing capabilities in either **Batch Edit akx_phase Metadata…** or **Create Report… Batch Edit akx_phase Metadata…** (See **Section 8.1.6**) allows the user to edit metadata for akx_phase files. **Create Report…** (See **Section 8**) allows the editing of metadata for akx_disp files.

7.7 Batch Convert

Converts *.akx_disp files containing phase data back to the *.akx_phase format. The key steps in using batch converting are:

1. Select a folder containing displacement files to be converted (**Source→Select…** menu item)
2. Perform the Batch Convert operation (**Action→Convert** menu item)

7.8 Batch Feature Detection

7.8.1 Using Batch Feature Detection

Batch Feature Detection allows the user to apply the Feature Detection function described in **Section 2.4.7** to a specified folder of displacement files. This batch function detects features according to options loaded in a settings file and edited in the batch feature detection tab window, then applies a customized mask based on the detected features. The batch Feature Detection screen is shown in **Figure 7.24**.

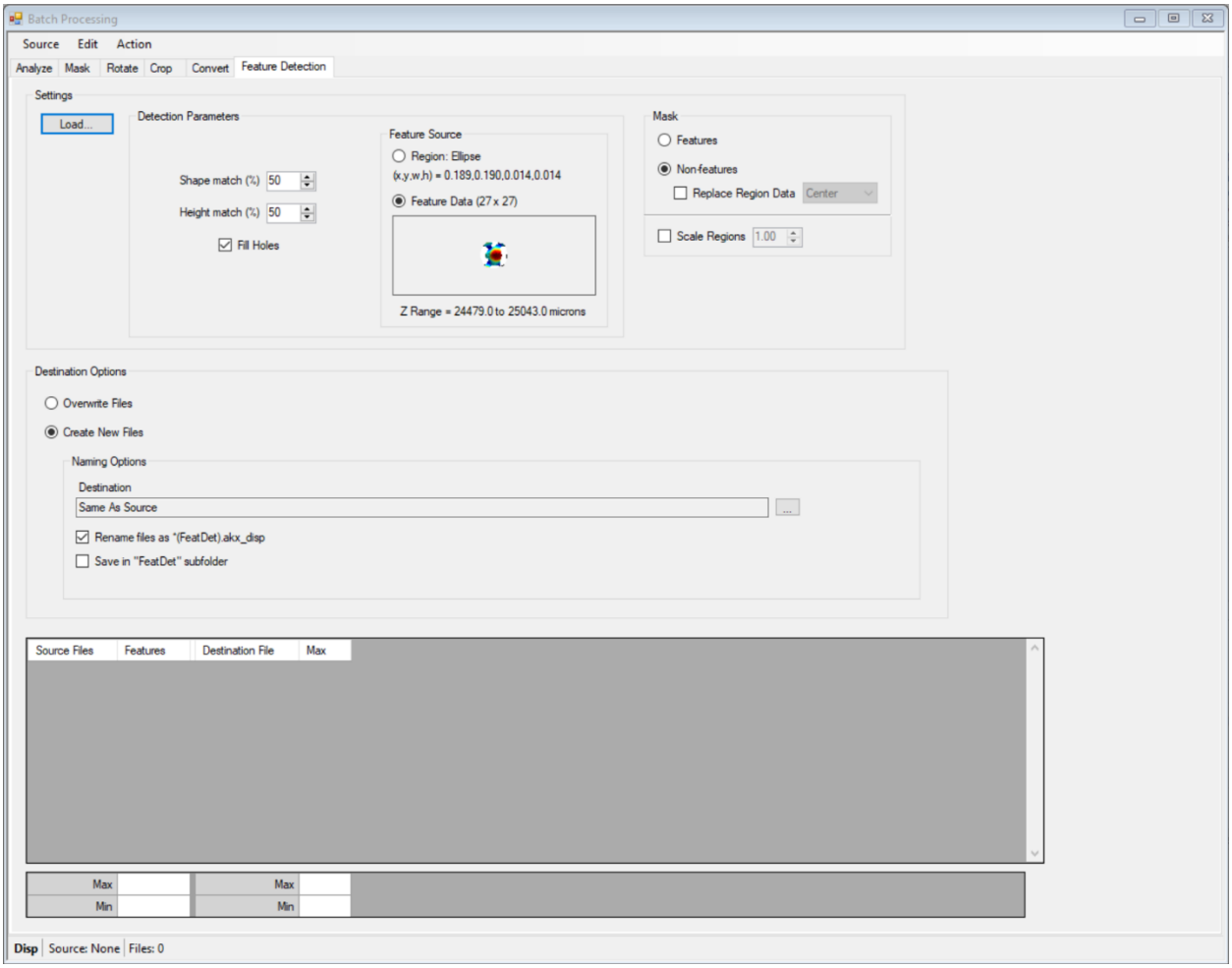


Figure 7.24 Batch Feature Detection Screen

The key steps in using Feature Detection are:

1. Select a folder containing *.akx_disp images to be masked (**Source→Select…** menu item)
2. Load in a Feature Detection Settings file and edit the settings if desired (see **Section 7.8.2**).
3. Select destination options (see **Section 7.8.3**)
4. Create and save results (**Action→Detect Features** menu item)

5. View results in Results table (see **Section 7.8.4**).

The Source, Edit, and Action menus for Feature Detection are all virtually identical to the Mask operation.

7.8.2 Feature Detection Settings

These Settings are all identical to those in the Feature Detection Parameter Window, which is described in **Section 2.4.7**. They are set by loading the Feature Detection Settings file, but can be edited by the user before batch detection.

The user cannot, however, edit the detection ROI as is possible in one-off Feature Detection. The region or detected feature present in the loaded settings file is used.

7.8.3 Destination and Naming Options

Overwrite Files	Resulting data overwrites original data files.
Create New Files	Saves resulting data to a new destination and/or with a new name. The original data files are unchanged.
Destination	Selects the output folder where resulting data is saved. Click on the ... button to the right to browse for the destination folder.
Rename files as *(FeatDet).akx_disp	Appends the string “(FeatDet)” to the end of the original filename for the resulting data.
Save In “FeatDet” sub-Folder	A single new folder named “FeatDet” will be created in the destination folder and all resulting data will be saved in this subfolder. This is only available when the destination folder is the same as the source folder.

7.8.4 Results Table

The last section of the Batch Feature Detection Tab is the results table. This table is similar in functionality to the results table for Batch Mask, which is described in **Section 7.3.9**. This table populates with a list of the source filenames when files are loaded, but does not fully populate until Feature Detection has been performed. Once populated, the table contains not only data about minima and maxima in the source and destination files, but also the number of features that were detected in each source file. All of this lets the user assess the quality of the feature detection operation.

8 Batch Reporting

As of Studio 8.0, Surface Analysis now incorporates the ability to batch create reports based on the metadata (**Section A.1.1**) from each displacement file being analyzed. The Create Report window has three subsections: Groups, Roi Selector, and Layout Settings. A File menu allows saving and loading settings as a *.akx_ReportSettings file. When loading settings, the user can choose to load Source Folders, Grouping Parameters, and/or Layout Settings (**Figure 8.1**).

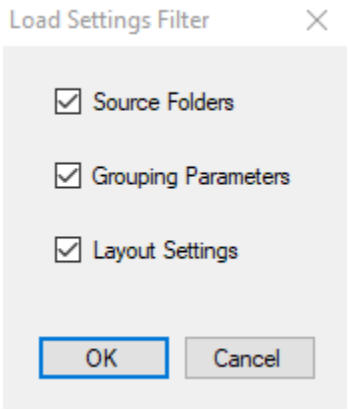


Figure 8.1 Load Report Settings Filter

As of Studio 8.6, Surface Analysis now allows for groups of room temperature data to be reported on. A radio button selection toggles between the thermal profile based and room temperature modes.

Note: The **Add file to profile…** function described in **Section 8.1.4** can be used to apply profile metadata to an orphaned measurement (typically a room temperature acquisition taken manually at the end of a profile).

8.1 Grouping by Metadata fields

Grouping can either happen before or after analysis. For purposes of analysis, multiple folders can be selected. See **Section 7.2.1** for details on how to add folders. The context menus are identical in the Group interface Folder List section as they are to the folder selection interface in Batch Analysis.

Note: If the Create Report function was opened from Batch Processing, the Folder List context menus will initially be the same as if there was no data, despite the analyzed data being present. New folders can still be added and removed, but the analyzed data cannot be removed or made inactive from the folder list.

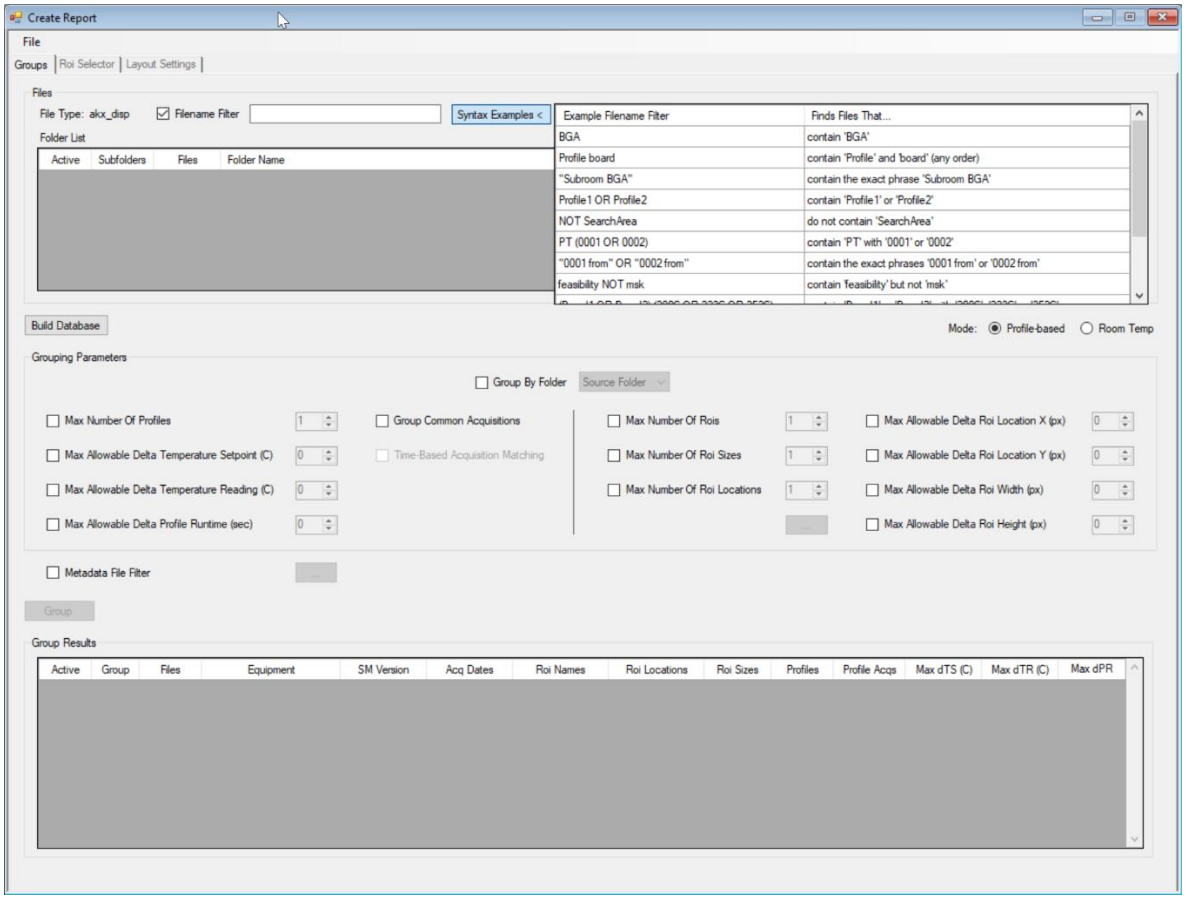


Figure 8.2 Grouping Window

Note: When the 'Room Temp' mode is selected, grouping parameters having to do with temperature profiles are disabled.

8.1.1 Files

Once the appropriate folders have been added to the Folder List, files can be filtered out by entering in search strings that the user desires. The "*" character can be added before, after, or in the middle of a string to denote parts of the filename that aren't important to match. Other search query syntax examples can be found in the table below.

Example Filename Filter	Finds Files That...
BGA	contain 'BGA'
Profile board	contain 'Profile' and 'board' (any order)
Subroom BGA	contain the exact phrase 'Subroom BGA'
Profile1 OR Profile2	contain 'Profile1' or 'Profile2'
NOT SearchArea	do not contain 'SearchArea'
PT (0001 OR 0002)	contain 'PT' with '0001' or '0002'
0001 from OR "0002 from"	contain the exact phrases '0001 from' or '0002 from'
feasibility NOT msk	contain 'feasibility' but not 'msk'

(Board1 OR Board2) (200C OR 223C OR 252C)	contain 'Board1' or 'Board2' with '200C', '223C' or '252C'
Roi0003 NOT ("Component Side" OR Demo)	contain 'Roi0003' but not with 'Component Side' or 'Demo'
Tray 1 OR NOT Cropped	contain 'Tray 1' or do not contain 'Cropped'
Profile (BGA OR ("Substrate Test"))	contain 'Profile' with 'BGA' Or 'Substrate Test'

Once the appropriate files are loaded into the folder list, the files must be indexed by clicking Build Database. After a database has been built, the files will be grouped together by acquisition index. If the user wishes to break the files into different groups for reporting purposes, one or more of the Grouping Parameters must be selected.

8.1.2 Grouping Parameters

1. Group By Folder: Source Folder or Full Path. Source Folder will use the name of the source folders to form groups. Any folder names that are repeated, but in different locations, will form one group. Full Path will use the unique Full Path for each input folder as the groups.
2. Max Allowable Delta Temperature Setpoint (C): Sets the max allowable difference for setpoint temperature. This will allow setpoint temperatures that are off by a user specified amount to be grouped together despite the difference. Common acquisition indices are compared and the greatest differential is referenced for grouping.
3. Max Allowable Delta Temperature Reading (C): Sets the max allowable difference for acquisition temperature. This will allow acquisition temperatures that are off by a user specified amount to be grouped together despite the difference. Common acquisition indices are compared and the greatest differential is referenced for grouping.
4. Max Allowable Delta Profile Runtime (sec): Sets the max allowable difference in acquisition time. This will allow acquisition times that are off by a user specified amount to be grouped together despite the difference. Common acquisition indices are compared and the greatest differential is referenced for grouping.
5. Time-Based Acquisition Matching: Only available if both ‘Max Allowable Delta Profile Runtime (sec)’ and ‘Group Common Acquisitions’ are selected. This parameter ignores acquisition index for grouping and instead groups based on time, referencing Max Allowable Delta Profile Runtime (sec). This option could be used if comparing two similar profiles where one profile had an extra acquisition inserted within the profile.
6. Max Number Of Profiles: Sets the max number of profiles in a group.
7. Max Number Of Rois: Sets the max number of Roi names in a group.
8. Max Number Of Roi Sizes: Sets the max number of ROI sizes in a group.
9. Max Number Of Roi Locations: Sets the max number of ROI locations in a group.
10. Max Allowable Delta Roi Location X: Sets the max difference in X axis location of the region of interest.

11. Max Allowable Delta Roi Location Y: Sets the max difference in Y axis location of the region of interest.
12. Max Allowable Delta Roi Width: Sets the max size difference along the X axis of the region of interest.
13. Max Allowable Delta Roi Height: Sets the max size difference along the Y axis of the region of interest.
14. Group Common Acquisitions: If multiple profiles are being reported on and the acquisition indexes aren't all coincident, this option will filter out orphaned acquisitions. In **Figure 8.3**, the profiles being reported on have varying numbers of acquisitions and in Profile 2, the first acquisition has been removed. By checking this option, only the acquisitions highlighted in yellow will be added to the report.

	Acquisition Index				
Profile 1	1	2	3	4	5
Profile 2		2	3		
Profile 3	1	2	3		

Figure 8.3 Group Common Acquisitions Example

Note: When in doubt about a grouping parameter's effect on the output groups, it can be quite useful to simply trial and error the setting in question to see the effect on the data.

8.1.3 Metadata File Filter

Files can be filtered out of the resulting groups by setting up filter/logic conditions in the Metadata File Filter. File filter queries can be saved and loaded as *.akx_query files in the Query Builder interface for future use.

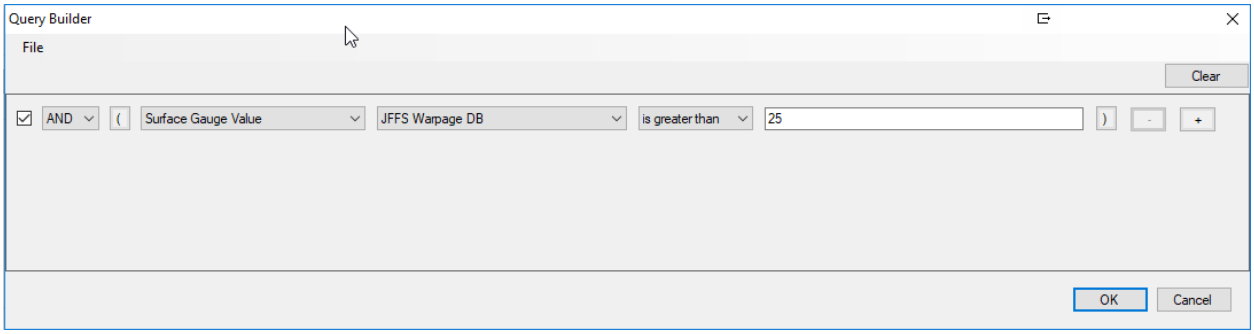


Figure 8.4 Metadata File Filter Query Builder

Multiple logic conditions can be set using AND/OR conditionals as well as parentheses around sets of conditions. Conditions can be added or removed using the + and – buttons. Virtually any metadata field within the displacement files can be queried against.

Note: The first query line AND/OR conditional is ignored.

8.1.4 Group Results and Editing Metadata

Once the files are indexed, all groups are shown in the Group Results section (**Figure 8.5**). This section lists pertinent information about each group, such as number of files, number of ROI names and locations, and number of temperature profiles. Individual groups can be activated or deactivated in this section, making it trivial to choose which ROIs go in the final report.

Note: An asterisk next to the number of files indicates that some files were excluded.

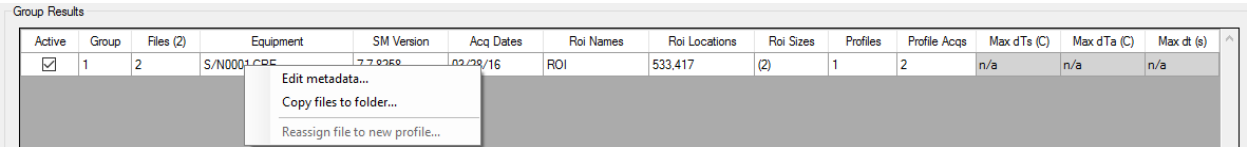


Figure 8.5 Group Results

The Edit Group Metadata window can be loaded from the context menu, or by double-clicking on any group. It allows the user to change ROI names and other metadata to better organize and label the report (**Figure 8.5**).

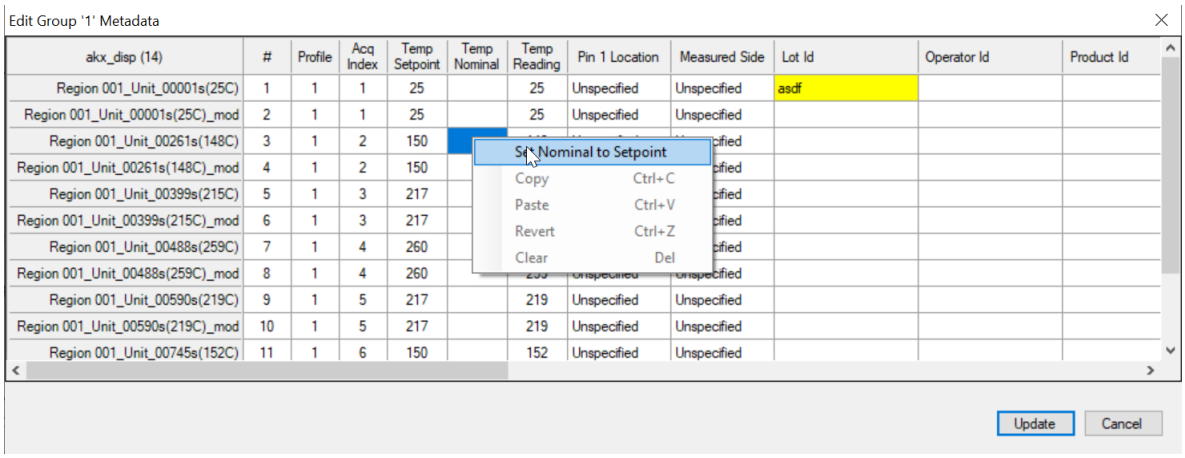


Figure 8.6 Edit Group Metadata

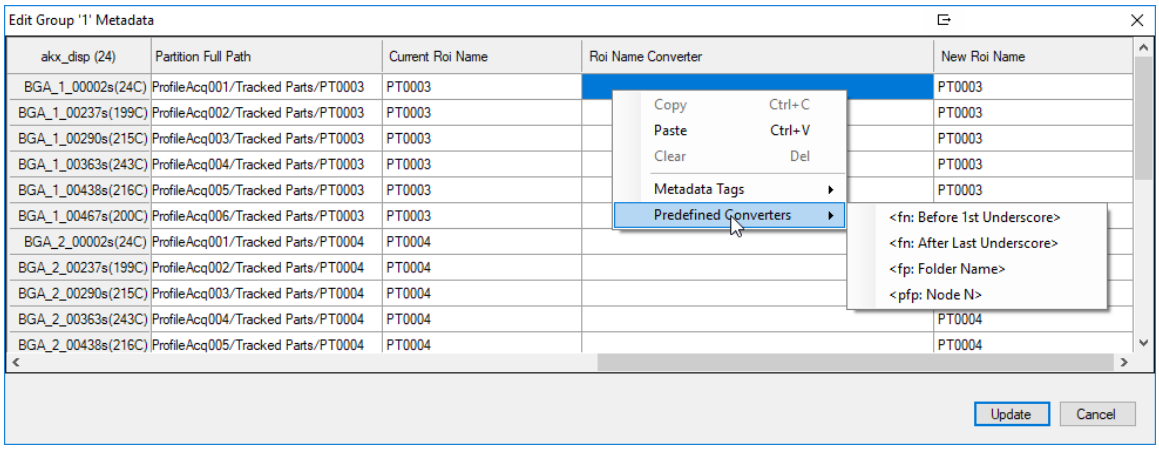


Figure 8.7 Edit Group Metadata - Roi Name Converter

In the Edit Group Metadata window that pops up (**Figure 8.6**), multiple metadata fields can be edited, including **Temp Nominal**, **Pin 1 Location**, **Measured Side**, **Lot Id**, **Operator Id**, **Product Id**, and **Test Id**. If a new value is entered into a field, it will be highlighted in yellow until the user clicks the **Update** button. The Temp Nominal context menu will allow the user to set its value to the Setpoint.

Note: Batch editing of Pin 1 Location and Measured Side is useful when preparing files for Interface Analysis.

The user can also choose what each file's **New Roi Name** will be via the **Roi Name Converter** column. The resulting ROI name, including the current values of entered tags, will be shown in the New ROI Name column. By default, the **<fn: Before 1st Underscore>** function provided will create a New Roi Name by parsing the input filename and using the string before the first underscore. Usually this corresponds to the **Test ID** based on how Surface Measurement creates filenames by default. In cases where this does not make sense, however, the user can enter a static string, or any of the metadata fields surrounded by Less Than or Greater Than signs. For instance, **<LotId>** would enter the Lot Id metadata information. A list of available Metadata tags is accessible by right-clicking on the Converter field. A few other predefined functions are also available via this same context menu (**Figure 8.7**). The user can also filter ROI names using custom regex converters, which are described in **Section 8.1.5**.

Strings can be copied and pasted into new rows. Also, multiple rows can be selected at once by shift-clicking, clicking and dragging, or Ctrl+clicking, allowing values to be pasted onto multiple rows at once. The keyboard shortcuts Ctrl+C and Ctrl+V can be used to copy and paste values, and Ctrl+A can be used to select all values in a column for editing.

Note: Any changes to file metadata will not be made until the **Update** button is pressed. To change ROI names based on a metadata update, it is necessary to update the metadata first and then reopen the Edit Group Metadata window.

If a file with no profile information is found from the input data, it is possible to add this orphaned file (a typical example would be data taken manually after a profile is complete) to an existing profile. In the Group Results section of Create Report, right-clicking on a group will bring up a context menu (**Figure 8.8**). If multiple files are orphaned, when Add file to profile… is selected, the user will have to choose which file to add to a profile (**Figure 8.9**). Likewise, once the file to be added is selected, the profile to which they will be added must be chosen (**Figure 8.10**). With the profile selected, the user can choose the **Setpoint**, **Temp Reading**, **Profile Runtime**, and **Acquisition Index** to add to the metadata for that file. In addition, the modified file can be renamed. Once the profile data for a file has been changed, it will automatically be moved to the correct group (**Figure 8.11**).

For files that are already assigned to a profile, these can be reassigned to other profiles if somehow their metadata is incorrect. The process for doing this is identical to adding a file to a profile.

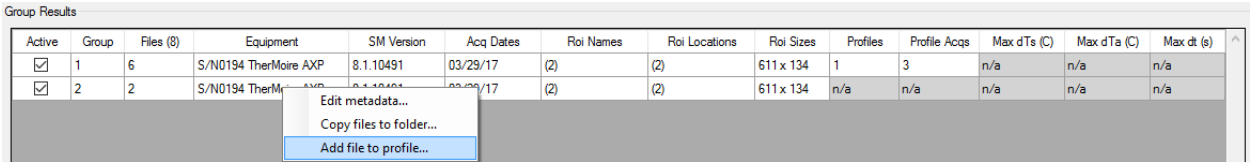


Figure 8.8 Group Results - Context Menu for Orphaned Files

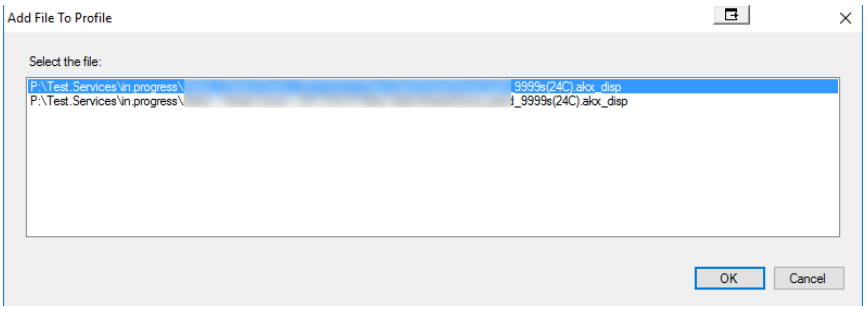


Figure 8.9 Add File to Profile - File Selector

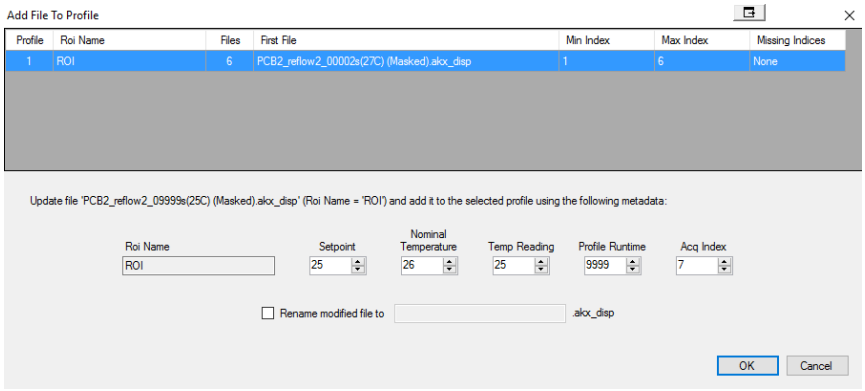


Figure 8.10 Add File to Profile - Profile Selector

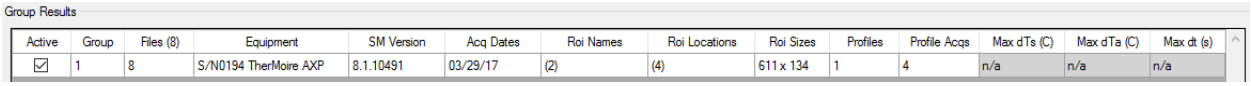


Figure 8.11 Group Results after Adding Files to Profile

8.1.5 Custom Converters

Figure 8.12 displays several custom regex converters, which allow easy extraction of specific character series from a filename and thereby easy ROI naming in the Edit Metadata window. The specific rules followed by custom converters are shown below.

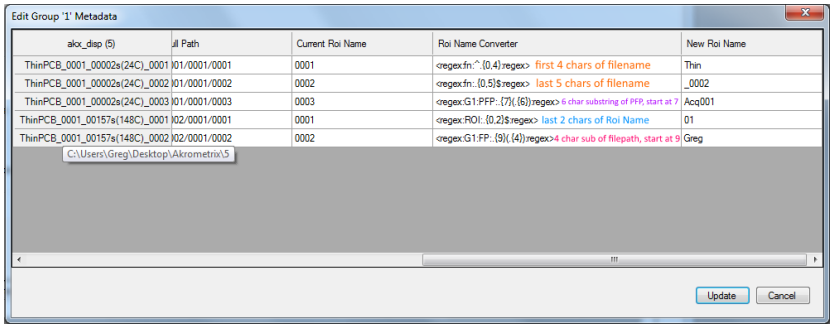


Figure 8.12 Custom Regex Converters

1. Custom converters begin with **<regex**: and end with **:regex>**
2. Custom converters can optionally include a 'Group Index' specifier, which may be required to get the desired regex match
   a. If no Group Index is specified, group index is 0 (default).
   b. Group Index is the first item included inside the regex syntax, and ends with a colon, specified as **G#:** or **G##:**
3. Custom converters can operate on 1 of 4 sources (specifiers are NOT case-sensitive): a colon is required after the source
   a. Filename, specified as **FN**
   b. Filepath (entire path, not including the filename), specified as **FP**
   c. Partition Full Path, specified as **PFP**
   d. Roi Name, specified as **ROI**
4. The regex expression is supplied AFTER the source colon.
5. Examples:
   a. **<regex:fn:^.{0,4}:regex>** the first 4 characters of the filename
   b. **<regex:fn:.{0,5}$:regex>** the last 5 characters of the filename
   c. **<regex:G1:PFP:.{7}(.{6}):regex>** a 6 character long substring of the partition full path, starting at index 7
   d. **<regex:ROI:.{0,2}$:regex>** the last two characters of the Roi Name
   e. **<regex:G1:FP:.{9}(.{4}):regex>** a 4 character long substring of the filepath, starting at index 9

Note: Strings start at index 0. This is important for any search involving a numbered index.

8.1.6 Batch Edit akx_phase Metadata

Metadata manipulation is also available for phase images in the Edit akx_phase Metadata window. This window (**Figure 8.13**) is accessible from **Tools→Batch Edit akx_phase Metadata**, similarly to the Create Report window. From this window, all profile reassignment and metadata editing described in **Section 8.1.4** is available for Phase images. Changing metadata for phase images can increase efficiency in data processing, since these metadata changes will not be overwritten if the data is reanalyzed, which would create new *.akx_disp files.

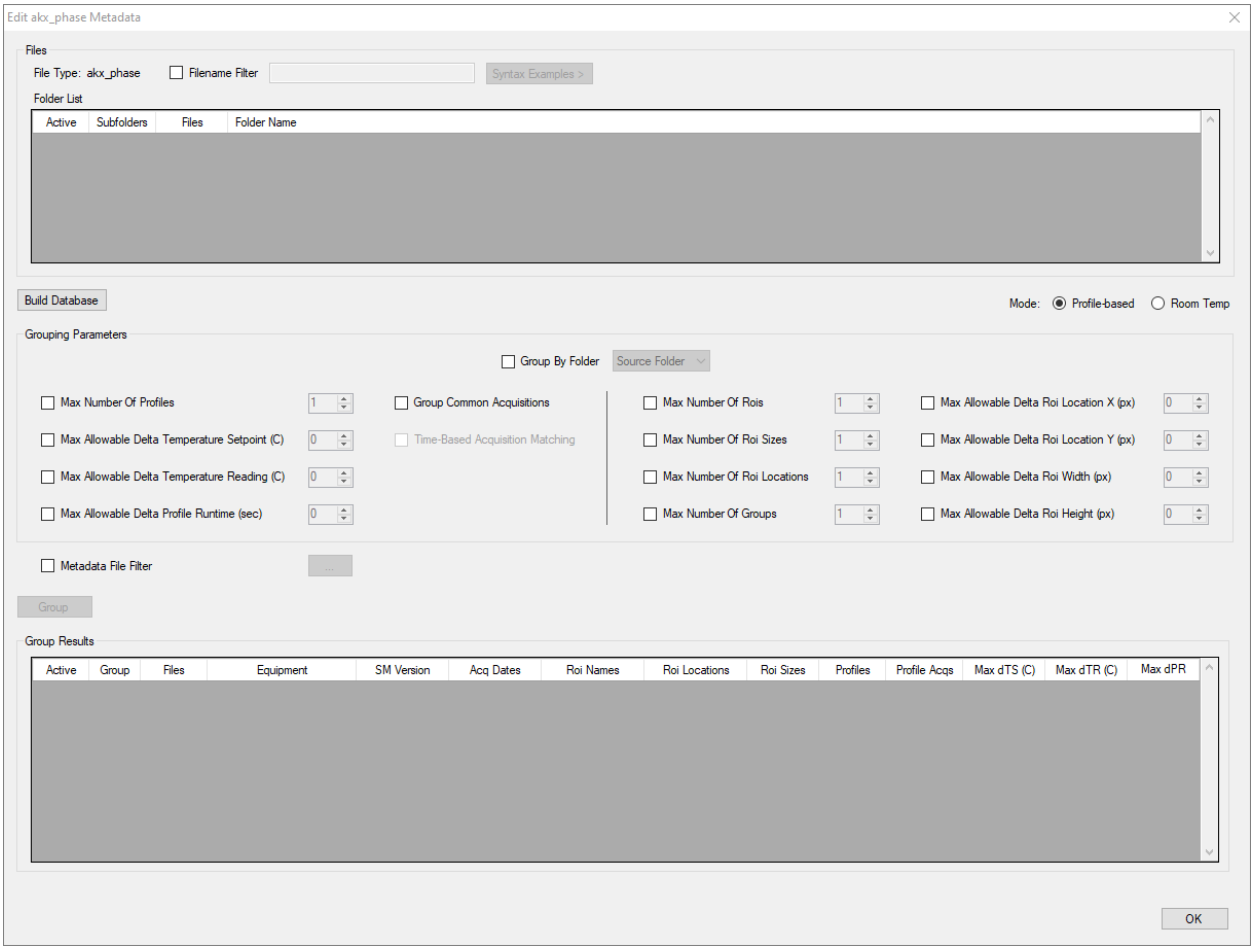


Figure 8.13 Edit akx_phase Metadata

8.2 Selecting ROI's

In the Roi Selector tab (**Figure 8.14**), the user can view 3D graphs of all active files, sorted into tabs by group. This tab allows the user can see a thumbnail view of a 3D graph for each active file, sorted into tabs by group. The user can then quickly find the minima and maxima, both overall and in each group, and discard any bad data before generating a report. From this tab, the user can also open any individual *.akx_disp file in the report, or the folder that contains said file. This is done using right-click context menus on each thumbnail image. In addition, files can be included or removed en masse with **Include All**, **Include None**, **Invert Included**, and **Include via metadata query…** commands.

The user can activate or deactivate individual ROIs in each group by clicking on them. In addition, entire rows or columns can be removed from the report entirely. These operations are the only things in this tab that affect the resulting report – the other options at the bottom of this window affect only the data displayed in the Roi Selector tab. These options include changing the size of the thumbnail images and editing the units of the Z-scale. Any changes made by the user will be applied when the Update button is pressed. The values of the minima and maxima for each group are displayed automatically, with the figures that have those values being highlighted in shades of purple – dark for Min, and light for Max.

Using the common Z-Scale menu, the user can decide whether Z-scales for the 3D graphs are shared within individual groups, within all files, or not at all. When Across Groups is selected as the common Z-Scale, the minimum and maximum overall Z-values will be displayed, as well as the range, and clicking on the Min and Max buttons will change the selected group to the one with the lowest or highest Z-value, respectively.

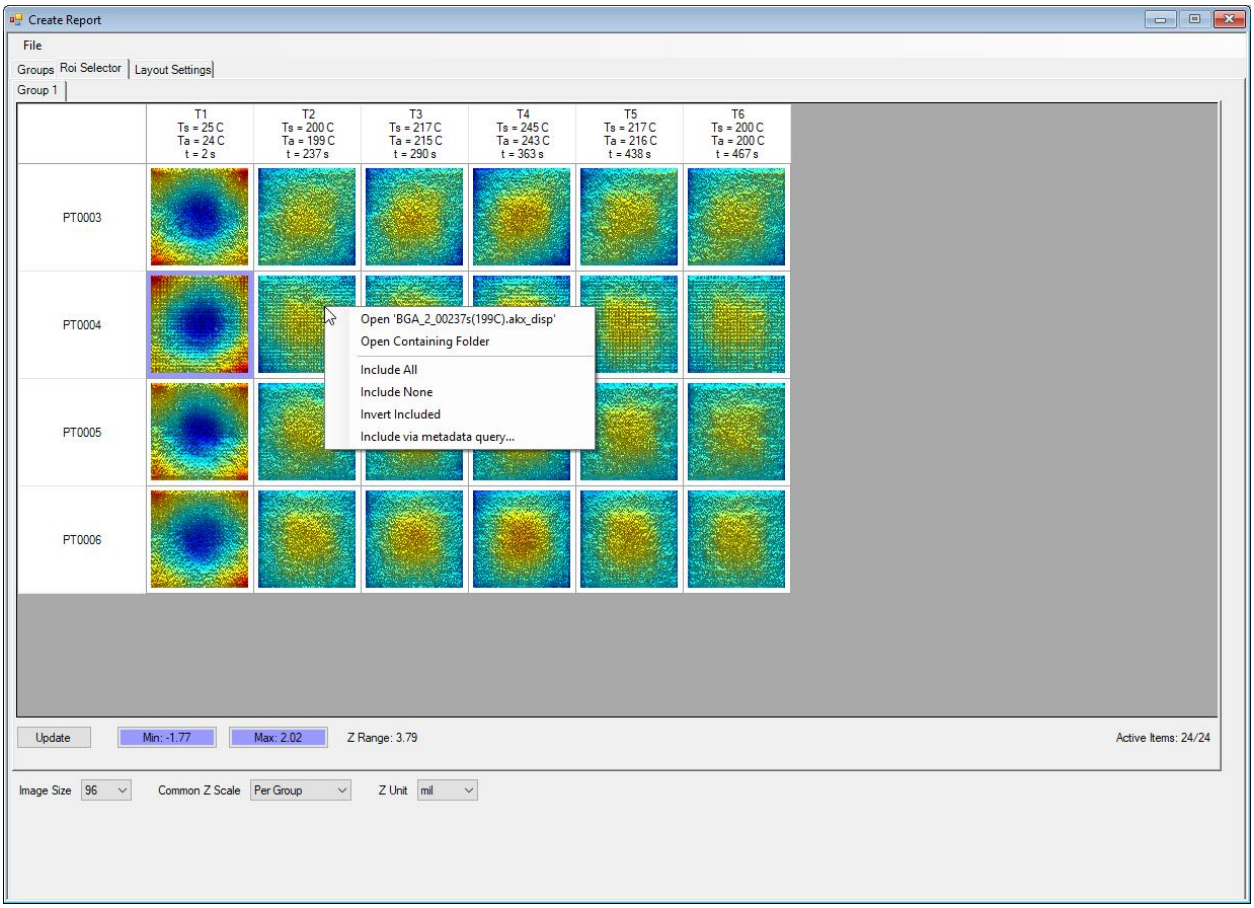


Figure 8.14 Roi Selector

8.3 Choosing Report Layout Settings

Once appropriate ROIs for the report have been organized into groups with any bad data discarded, the user can use the Layout Settings tab to determine the formatting and displayed data of the final report. The user also has the option to deactivate groups without changing other settings, making it simple to create both overall reports and

individual reports for different groups. The user has a variety of options in this tab, separated into several subsections.

8.3.1 Group and Plot Selection

The uppermost section of the Layout Settings tab offers several useful options. The user can choose which groups to include in a report using the Active checkboxes. They can see a variety of information about the group, including Z-Range, group number, number of ROI names, and the name of the first file in the group. Mousing over some of these cells will show a tooltip with further information, such as a list of all the ROI names, or currently selected Gauge Plots.

Further to the right, this section also contains several editable labels that can appear in the report. These can be used to create titles for individual images, series labels in the legends of Gauge vs temperature plots, page titles and subtitles, and footers. Any of these options can use metadata tags like <RoiName> and <PageGraphType>. The labels will appear only on pages with data for the selected group, and the report will automatically separate groups into different sections.

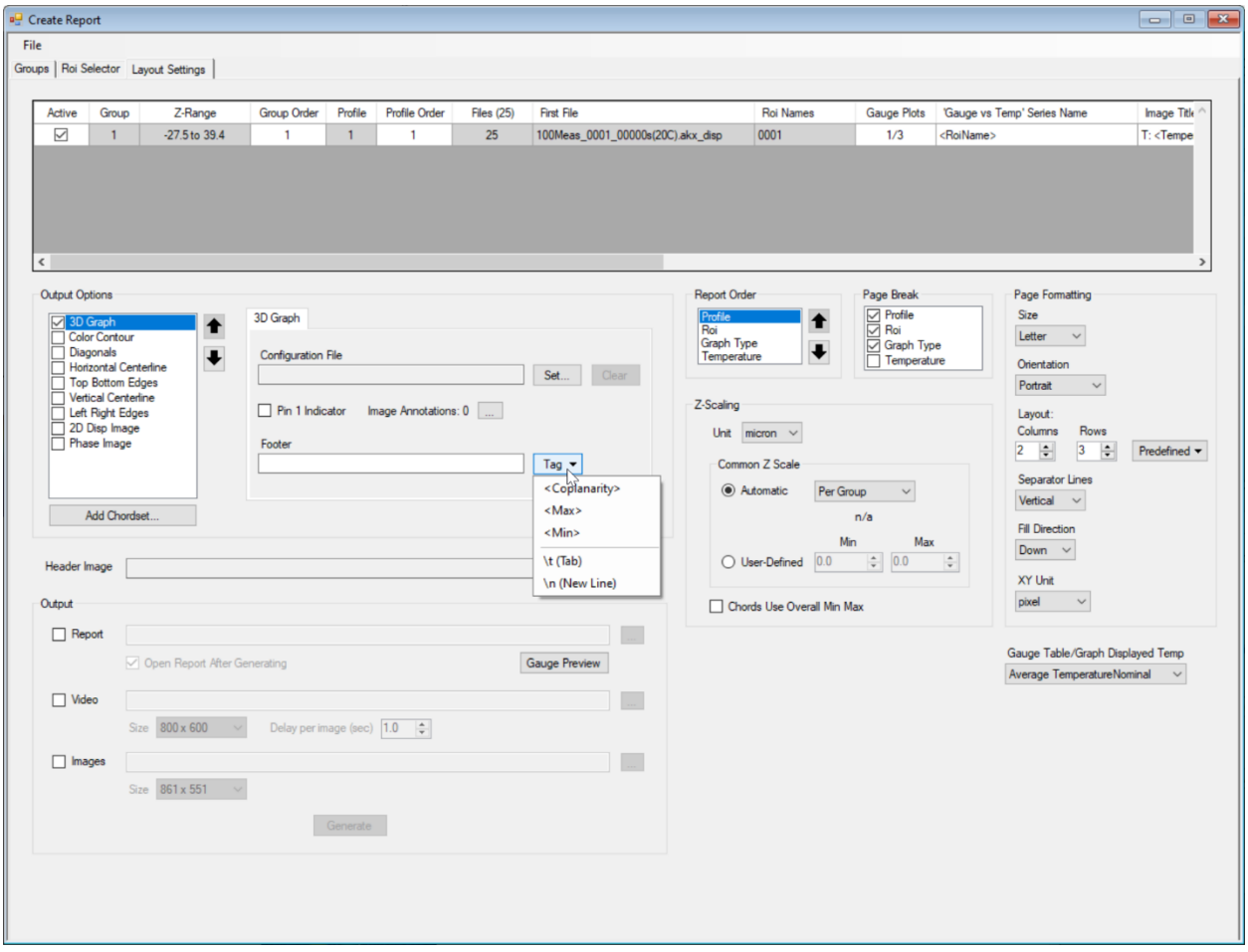


Figure 8.15 Layout Settings Tab

The user can also click on the Gauge Plots cell for any group in this section. This will open the Gauge Plot Selector window shown in **Figure 8.16**. From this window, the user

can choose which of the calculated gauges to display in the report, and which statistical values should be displayed for those gauges. These values can be calculated for each ROI, for each temperature point, or globally throughout a group. Selecting an option by clicking on it and moving it up and down in the list with the arrows will reorder the gauge plots in the report.

Note: If a desired gauge is not in this list, then it was not calculated during analysis. In Batch Processing, the user must select whichever gauges are desired in the final report, so that they are present in the *.akx_disp files that are used to build the report.

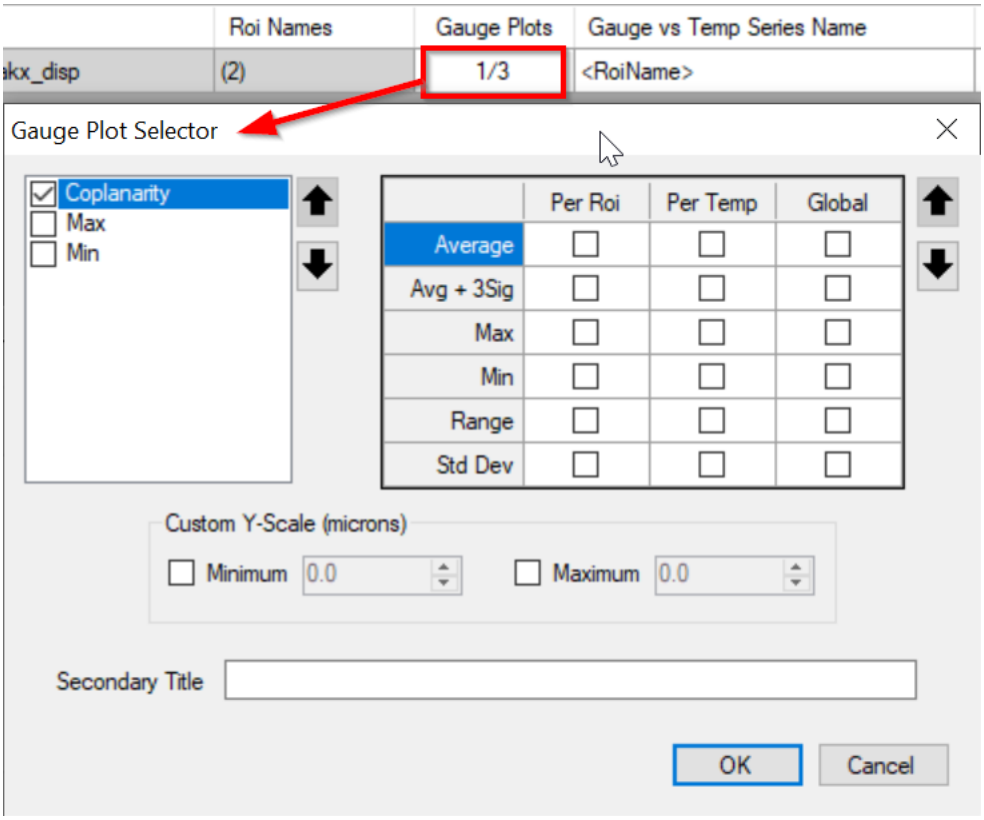


Figure 8.16 Gauge Plot Selector

8.3.2 Output Options

This section allows the user to decide what graphs will be shown in the report, how they are configured, and what footer information the graphs have. Editing the configuration of graphs requires loading a previously created *.akx_2dConfig or *.akx_3dConfig file (depending on graph type) for each graph that is changed from its default layout.

The Normalize checkbox causes all 2D chord plots to be displayed with the endpoints referenced to zero. The Pin 1 Indicator checkbox causes all images of the part to have a dot indicating the location of Pin 1. This function uses the Pin 1 metadata for the file, so requires that information to be specified. Image Annotations can be added as described in **Section 7.2.4**.

Finally, to add footers to the graph, the user can choose from a list of tags that changes with the selected graph. The user may also use tab (/t) and new line (/n) tags to format the footers in the final report.

Note: In addition to the default output plots, custom chord plots can be loaded in using *.akx_chordset files and plotted like any other 2D graph.

8.3.3 Report Order

This option determines what data ordering takes precedence within a group. The default is Profile > ROI > Graph Type > Temperature. These options change to Acquire Timestamp > ROI > Graph Type when in 'Room Temp' mode.

8.3.4 Page Break

This determines after what data page breaks occur. The default is Profile, ROI, and Graph Type, but not temperature. These options change to Acquire Timestamp > Graph Type > ROI when in 'Room Temp' mode.

8.3.5 Z-Scaling

This section allows the user to choose the Z-scale for displacement graphs. They can choose the units of Z, and either enter a custom Z-scale or choose an automatic Z-scale. The automatic options are None, Per Group, and Across Groups. The 'Chords Use Overall Min Max' option determines whether 2D chord plots use individual minima and maxima in their z-scales, or the overall minima and maxima across all groups.

8.3.6 Page Formatting

1. Size – Letter or A4
2. Orientation – Portrait or Landscape
3. Layout: - Choose the # of columns and rows for plot pages. Predefined options for 6/page or 24/page
4. Separator Lines – Option to show lines separating plots. Options are None, Horizontal, Vertical, or Both
5. Fill Direction – This option lets the user decide whether initial population of figures and graphs is top-bottom and then left-right, or vice versa.
6. XY Unit – This lets the user determine the XY units on each graph if a lateral resolution is specified in each file. This would allow the graph XY axes to be shown in physical units instead of pixels.

8.3.7 Gauge Table/Graph Displayed Temp

This allows the user to choose from three temperatures for gauge tables and graphing gauges: Average reading temperature at that time, nominal temperature chosen in Profile Generator, or the Setpoint temperature of the profile.

8.3.8 Header Image

This allows the user to choose a header image to be placed at the top of each page.

8.3.9 Output

Once all settings have been selected, the user can use the Output section to determine what results will be generated. There are three possible types of output – Report, Video, and Images – and any or all of them may be generated at one time by selecting their check boxes and pressing **Generate**.

Generating any output requires appropriate save data, which the user is automatically prompted to enter if none has yet been added. Report and Video need both filename and destination folder, while Images only needs a destination folder. The first time that a filename or destination folder is entered, it will be shared to the other outputs. The **…** buttons after each option can be used to independently edit destinations and filenames for each output.

1. **Report –** This is a pdf report containing all selected images and gauges. It is the most common option, and the one to which many of the customization options in the Layout Settings tab are dedicated. **Figure 8.17** shows an example. Checking **Open Report After Generating** allows the user to immediately see the results when the report has been created.
2. **Gauge Preview** – This button generates a pdf containing gauge results based on current settings but no images. Since no images are saved, this allows the user to more quickly see how the groups are organized and what the overall numerical results look like. This button works regardless of whether Report has been selected as an active output.
3. **Video –** This is a video file which strings together all gauge plots and all selected images. The user can choose image size and the delay between images in the video.
4. **Images –** This option saves all images selected in Output Options to a user selected folder. The user may select the image size.

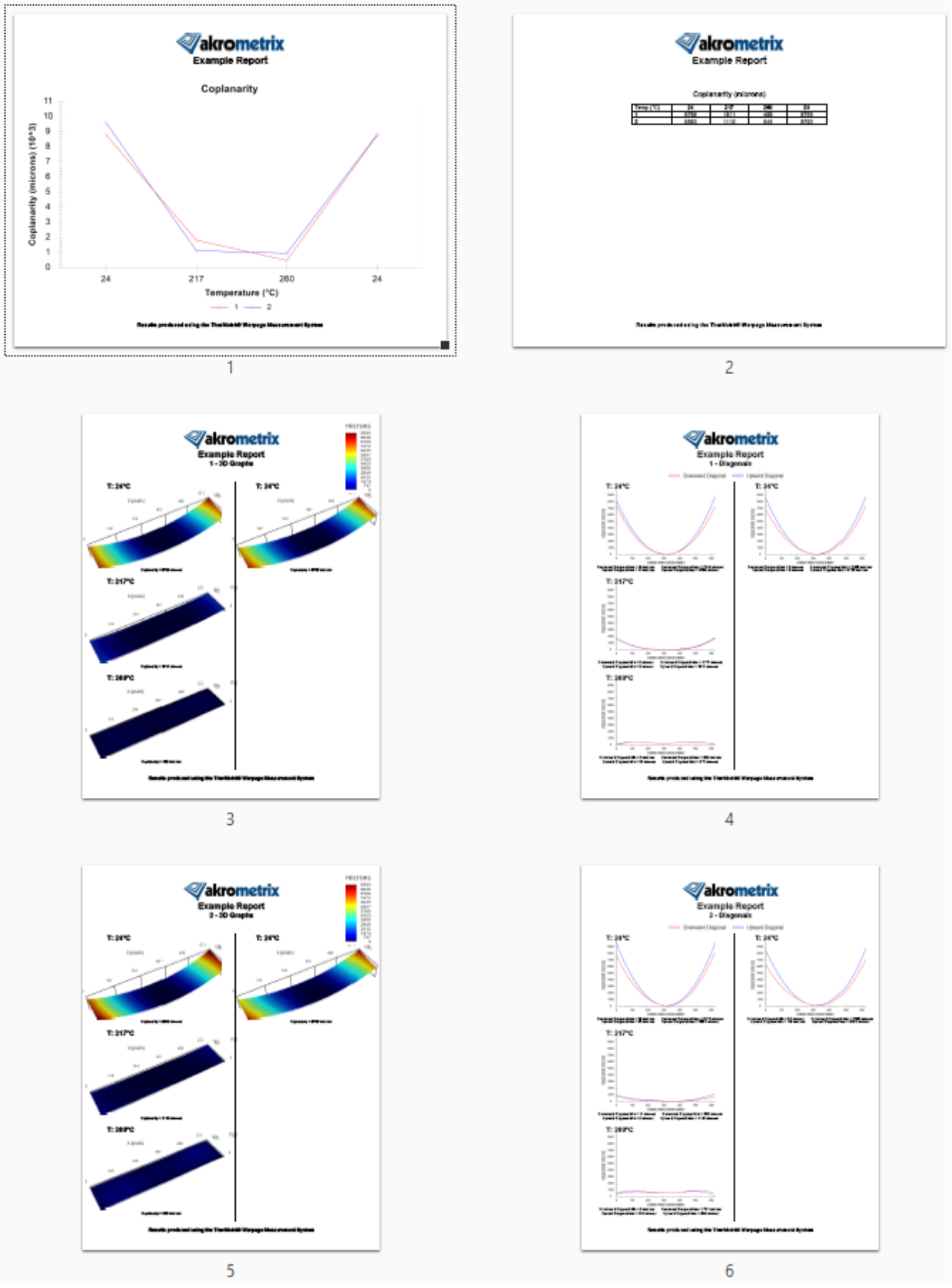


Figure 8.17 Example Report with 6 images per page

9 Manual Reporting

Formerly an independent application in the Akrometrix Studio software platform, the Manual Report feature is now a part of Surface Analysis. It consists of a simple 6-up graphical layout tool (**Figure 9.1**) for creating reports from static image files. Typically, these are 3D, 2D, and Temperature Profile graphs produced by other Akrometrix software applications, but any image file can be used. Output PDFs created feature multi-figure portrait-style report pages, with up to six graphs and two legends on “Letter” sized paper.

Figure 9.1 Manual Report Window

The report page layout consists of eight image locations and nine textboxes. The larger image locations are designed to hold the typical 3D or 2D plots created in Surface Measurement or Surface Analysis. In addition, any *.bmp, *.png, *.jpg, or *.tif image files can be loaded as well. The smaller image locations near the top are designed around holding the typical 2D (Chord) and 3D legend image files, respectively.

The textboxes control the Main Title, Secondary Title, individual Image Titles, and Footer text for each page. As pages are added to the report, page navigation is accomplished with the Previous Page / Next Page (< >) buttons found at the bottom of the screen below the footer textbox. The current page and total number of report pages are indicated between these buttons.

9.1 Adding Page Contents

Images are added to a report page by dragging and dropping a selected image file or files from a Windows Explorer window onto the desired destination image location. Alternatively, left clicking on the image location itself will bring up a load image dialog to browse to the file.

If multiple files are selected (using Ctrl or Shift), image locations are filled in numerical order (starting with the dropped destination location) according to the file selection order.

Individual image locations are also assigned by right clicking on the location and selecting Load Image… from the popup menu that appears. A standard Windows Open File dialog box is shown allowing the user to select a file.

After an image has been assigned to a particular location, its filename pops up in a tool tip whenever the mouse pointer is paused over the image. The selected image (outlined in blue) can be viewed full-size by pressing Enter or double clicking on the image location. The full-size view is closed by pressing Enter, clicking on the OK button, or pressing “X” at the upper right of the window.

In addition to entering new text, the textbox controls allow the user to select previously entered text from a pull-down list. Typed text is added to the list whenever a textbox loses its focus.

9.2 Editing a Report

The Edit menu allows the user to Add, Insert, and Delete report pages as well as remove all images in the report. Adding a page appends it the end of the report while inserting one places it before the next page relative to the currently viewed page. Any new page added or inserted copies the text entry fields from the currently viewed page, allowing patterns to be easily repeated and altered. In addition, the currently viewed page textbox entries can be duplicated to all report pages.

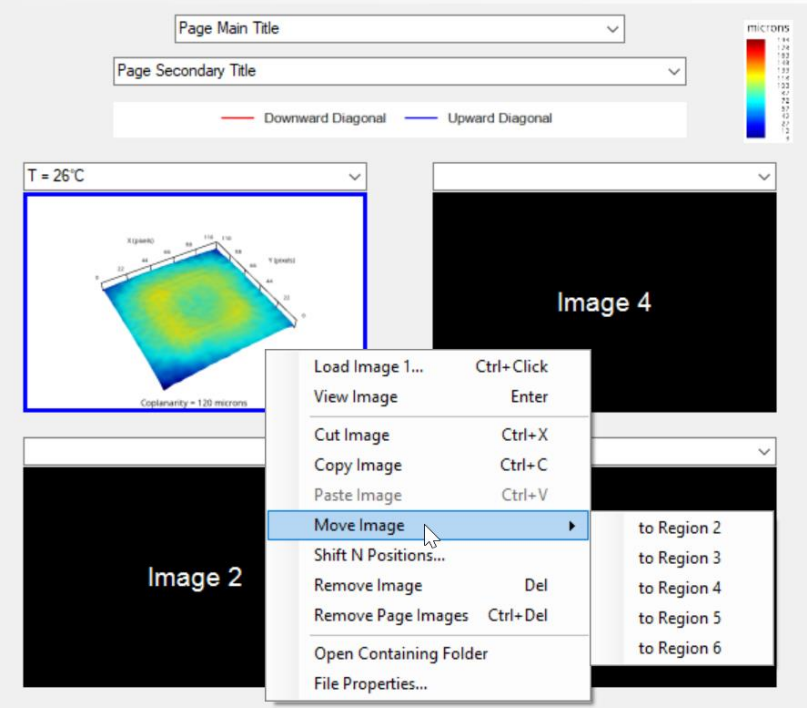


Figure 9.2 Manual Report Image Context Menu

Individual images can be easily moved within the same page. Image locations are also manipulated with a right click context menu allowing Cut, Copy, Paste, Delete, and Clear operations, among others (**Figure 9.2**).

9.3 Saving the Report

After all report pages and titles have been assigned, the report can be saved by going to **File→Save**. This will save a *.akx_ManualReportContent file with the image locations and text box field entries so the report can be loaded/modified/generated at a later date.

Note: The*.akx_ManualReportContent file only contains pointers to the image file locations. If the image files are moved or deleted from these locations, the image files will not be displayed when the file is loaded.

If a PDF version of the report is needed, select **File→Generate Report**. A standard Save As dialog box prompts the user to specify a path and filename for the report. After clicking Save, the report will be created and opened in the default system PDF viewer. A new blank report can also be started via the **File** menu.

10 File Finder

File Finder allows searching for phase and displacement files previously captured and saved to disk. Although Windows allows searching of files based on filename and file extension, it does not have access to the metadata fields within Akrometrix files. File Finder enables any metadata field within the phase or displacement file to be searched, enabling more detailed search queries.

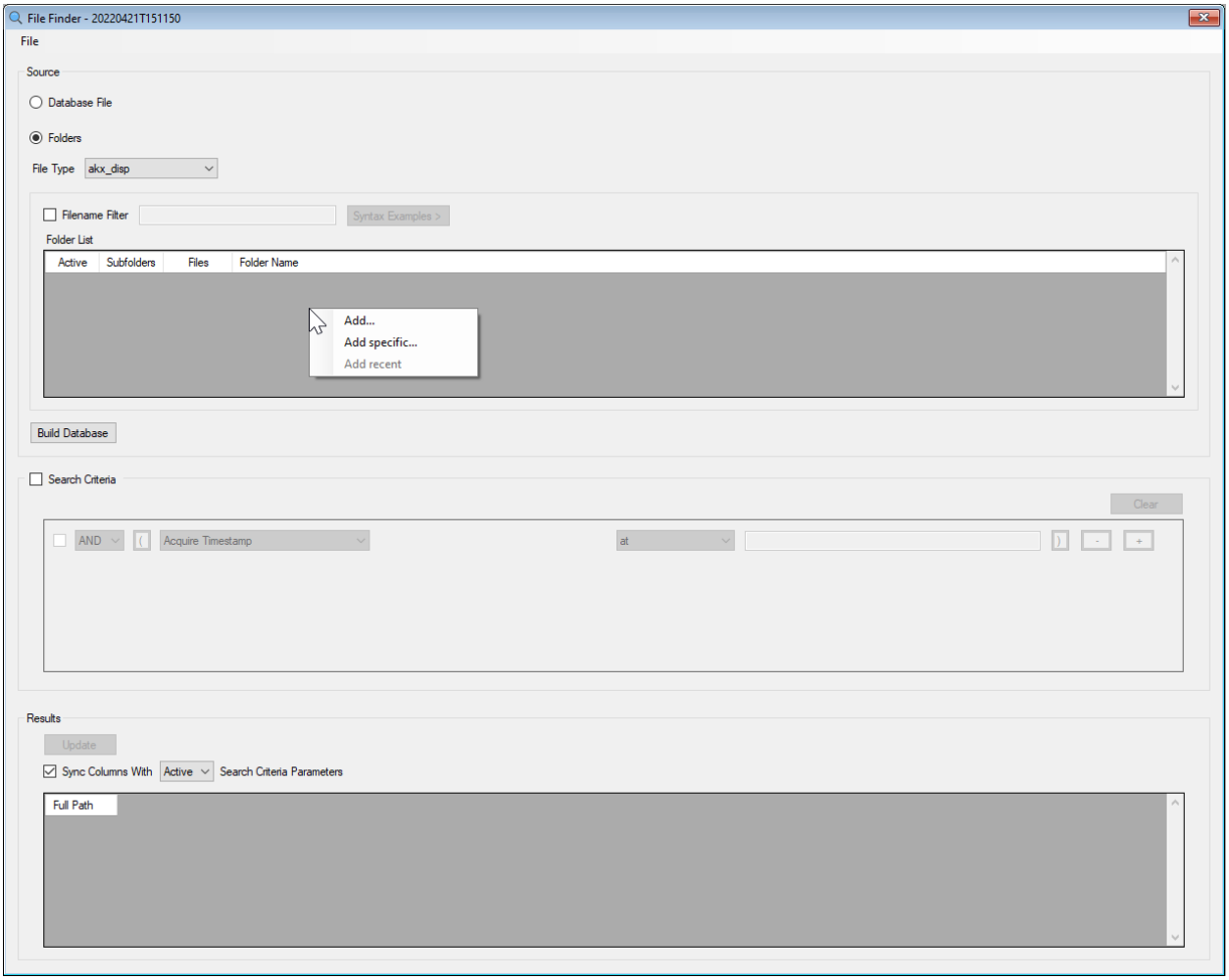


Figure 10.1 File Finder window

Folders can be dragged into the Folder List section of the interface, or there are Add buttons in the right-click context menu (see **Figure 10.1**). This interface works the same way as in Batch Processing (**Section 7.2.1**). Multiple folders can be added at once and right-click context menus allow interaction with each added folder to add from that folder location, delete the folder, refresh it, etc.

Once a folder or set of folders is added, a database must be built using the Build Database button. This indexes all the individual files in the folders and produces a database, in memory, of the filenames and their metadata contents. This Database file can be saved and loaded (**Figure 10.2**) again for future queries, instead of having to re-

index. This can save substantial indexing time when dealing with hundreds or thousands of files.

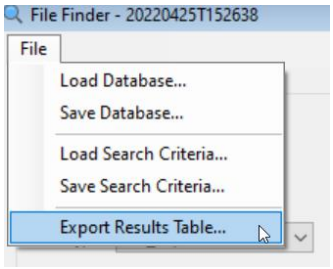


Figure 10.2 File Finder File Menu

Next, Search Criteria can be specified (**Figure 10.3**) to filter out results based on metadata fields. This metadata filter function works exactly the same as in Batch Reporting (see **Section 8.1.3**). When all filters have been added, the Update button in the Results section will display all files in the folder list that meet the specified criteria, either Active or All, depending on the drop-down selection. The Search Criteria can be saved and loaded via the File menu (**Figure 10.2**).

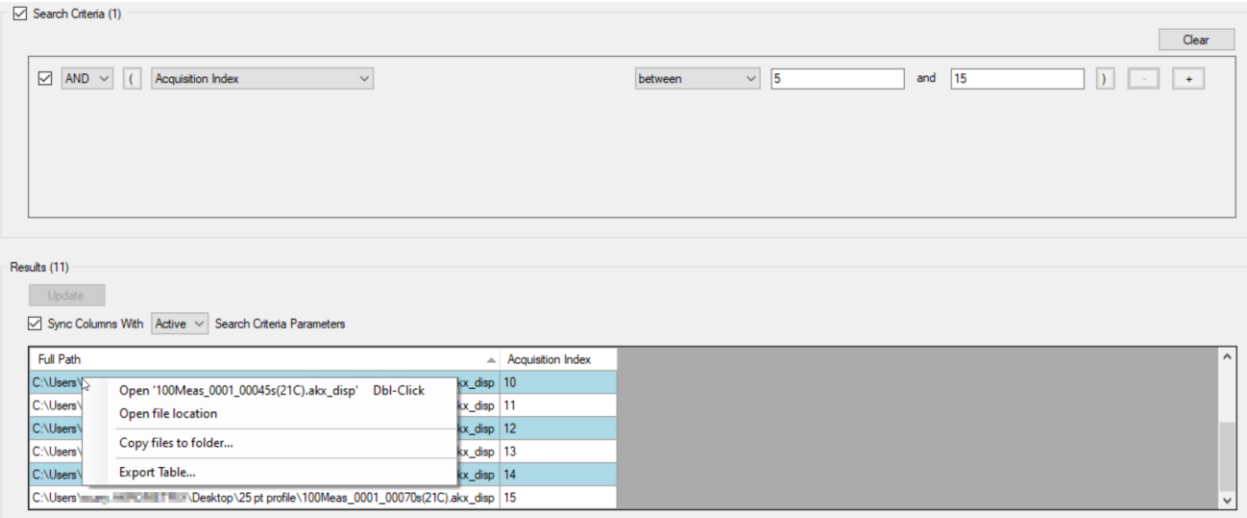


Figure 10.3 File Finder Search Criteria and Results

The resultant list of files can be opened via the file list context menu (**Figure 10.3**), copied to another folder, or saved as a *.csv file.

11 Troubleshooting

As with any measurement system software, the **Surface Analysis** program has its limitations. These limitations exist mainly because the analysis software is sensitive to patterns it was not designed to interpret, which is typical of any software using pattern recognition.

11.1 Failure to Correctly Interpret the Phase Image

After acquiring a phase image, a procedure called “unwrapping” is applied to the phase data (See **Akrometrix Optical Techniques and Analyses 101**). The unwrapping process removes the 2π discontinuity by examining the nearest neighbors’ pixel phase values starting at the center pixel. With the sequentially dependent nature of the unwrapping process, the height at all the pixels in an entire image can be related to one origin pixel. Conversion from the unwrapped phase image to vertical displacement is simply multiplication of each pixel phase value by the calibration factor.

Problems arise when an error occurs at one point in the unwrapping process, either by incorrectly identifying a phase discontinuity or missing a discontinuity that has occurred. Once a problem occurs, all pixels downstream of the error point are offset from their correct value by the same increment of one full fringe cycle.

11.1.1 Symptoms

Unwrapping errors are propagated downstream of the error point. These errors appear in the 3D surface plots as ridges, troughs, or plateaus in the displacement surface. Two examples of such cases are shown in **Figure 11.1**, where the error originates from a step condition on the sample surface.

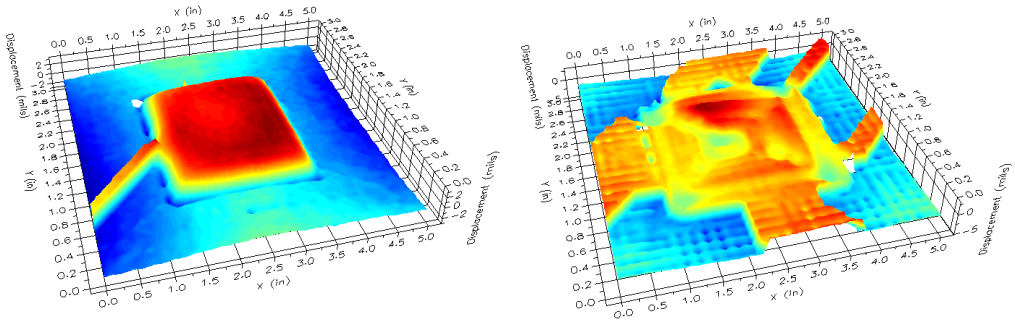


Figure 11.1 Surface Plots with Unwrapping Errors

11.1.2 Cause

Unwrapping errors can occur at steps (i.e. vertical discontinuities in the sample surface). A step may be defined as a region where fringes are so closely spaced that they cannot be resolved by the video camera due to a rapid height change on the sample surface. Typically, fringes less than 5 pixels in width cannot be resolved. The **Surface Analysis** program is unable to determine the height at a step larger than approximately half a fringe height since the relative order of the fringes on the two surfaces cannot be determined. Unwrapping errors can also occur in regions where there is poor fringe

information or at the transition from such regions to regions of good phase information; including holes, shadows, pieces of tape, etc.

11.1.3 Solutions

1. The simplest, and best solution is to exclude error-causing features from the ROI. Adjust the position and size of the ROI to exclude these features.
2. Apply a mask to the phase image over problematic areas to prevent them from being analyzed. Follow the directions given in **Section 3.2**.

Note: Aggressive masking may create isolated data "islands" that cannot be crossed by the normal unwrapping algorithms. In this case, the user can alter the Unwrapping Parameters to properly display isolated data. See **Section 4.6**.

3. Use Second Differences Phase Unwrapping and a high Threshold to remove low quality phase data from the analysis. See **Section 4.6.3**.
4. Use the filtering option to help eliminate some unwrapping errors. Filtering smooths the phase image before unwrapping. Because filtering can smear out fine detail in the displacement surface, it should be applied to the analysis only to the extent necessary to eliminate undesirable phase unwrapping artifacts.

Appendix A Miscellaneous Information

A.1 File Formats

Akrometrix Surface Analysis loads and saves data with the *.akx_* extension. For a more detailed breakdown of **Surface Analysis** specific formats please see the table below. Image export formats are exclusively *.png with varying filename postfixes to further denote their origins.

Extension	Contents
*.akx_phase	A single phase image with associated metadata. May optionally contain cropped versions of supporting data: intensity, and/or reference displacement
*.akx_disp	A single displacement data matrix with associated metadata. May optionally contain cropped versions of supporting data: phase, intensity, and/or reference displacement
*.akx_partition	Partition file (standard XML format)
*.akx_3Dconfig	Configuration file for 3D plot
*.akx_2Dconfig	Configuration file for 2D plot
*.akx_chordset	Chord set (standard XML format)
*.akx_recipe	Stores batch processing settings for recall later.

A.1.1 Metadata Fields

Metadata fields embedded in *.akx_phase or *.akx_disp objects can be used in building filenames, output paths, and report labels in various places in Akrometrix Studio applications. Some of the more commonly used metadata fields are described below.

Metadata Field	Description
<RoiName>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**
<LotId>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**
<OperatorId>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**
<ProductId>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**
<SerialNumberId>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**
<TestId>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**
<Pin1Location>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**
<MeasuredSide>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**

<InterfaceLocation>	User defined. Editable in both **Surface Measurement** and **Surface Analysis**
<TemperatureNominal>	User defined when creating a profile in **Profiler Generator**. Also editable in **Surface Analysis**
<TemperatureReading>	Any thermocouple data for the acquisition (can include up to 16 temperatures in the case of a CRE measurement). With no suffix, this metadata tag will provide TC1 data, but a two digit numerical suffix, such as “02” will provide the data for the corresponding thermocouple.
<TemperatureSetpoint>	User defined when creating a profile in **Profile Generator**
<ProfileSecondsAndTemp>	Time/temperature when a phase/disp file was acquired.

Other metadata fields such as Equipment Model, etc. are available in the Properties window of any phase or displacement image (**Figure 2.4**). Any entry in this list can be surrounded by “<” “>” symbols to indicate to the application to use that metadata field in populating the corresponding text entry area. In addition, any gauge value can be added in the same way.

A.2 Keyboard Shortcuts

Shortcut	Command	Action
Main Window Shortcuts		
Ctrl+O	**File→Open**	Open a new *.akx_phase or *akx_disp file
Alt+F+X	**File→Exit**	Exit the Surface Analysis program
F1	**Help→User Manual**	Open the User Manual
Phase Window Shortcuts		
Ctrl+C	**Copy (ROI)**	Copy ROI
Ctrl+V	**Paste (ROI)**	Paste ROI
Ctrl plus arrow key increases the ROI size by one pixel in the indicated direction.		
Alt plus arrow key decreases the ROI size by one pixel in the indicated direction.		
1-4	**Advanced→View→Intensity 1-4**	Show Intensity Images 1-4
P	**Advanced→View→Phase Image**	Show Phase Image
S	**Advanced→View→Surface Image**	Show Surface Image
Ctrl+		Zoom in to phase image
Ctrl-		Zoom out of phase image
Ctrl+M	**Advanced→Mask→New**	Create a new mask
Ctrl+Shift+M	**Advanced→Mask→Load**	Load a mask
Ctrl+R	**Advanced→Partition→New**	Create a new partition
Ctrl+Shift+R	**Advanced→Partition→Load**	Load a partition
Ctrl+B	**Advanced→Unwrapping Parameters→Add Bridge**	Create a new phase bridge
Ctrl+K	**Advanced→Chord→Add Chord**	Create a new chord
Ctrl+Shift+K	**Advanced→Chord→Load**	Load a chord set
Shift+T		Create a chord along top edge of the image
Shift+B		Create a chord along bottom edge of the image
Shift+L		Create a chord along left edge of the image
Shift+R		Create a chord along right edge of the image
Shift+D		Create downward diagonal chord (upper left to lower right corner) on the image

Shift+U		Create upward diagonal chord (lower left to upper right corner) on the image
Shift+H		Create a chord along the horizontal centerline of the image
Shift+V		Create a chord along the vertical centerline of the image
3D Window Shortcuts		
Ctrl+S	**File→Save…**	Saves the 3D data as a displacement file (*.akx_disp)
Ctrl+I	**File→Save Image…**	Saves the 3D data as an image (*_3D.png)
Ctrl+P	**File→Print…**	Prints the image
Ctrl+C	**Display→Copy View**	Copies the current display window viewing angle and magnification to the Clipboard.
Ctrl+V	**Display→Paste View**	Applies the viewing angle and magnification saved to the Clipboard to the current display window (only appears after **Copy View** is used).
Esc	**Display→Reset View**	Resets the Zoom back to 100%
Ctrl+Alt+C	**Display→Configure…**	Opens the 3D graph configuration panel
Batch Processing Window Shortcuts		
F5	**Edit→Refresh Source Folder**	Allows the user to update the list of source files since the folder was originally selected