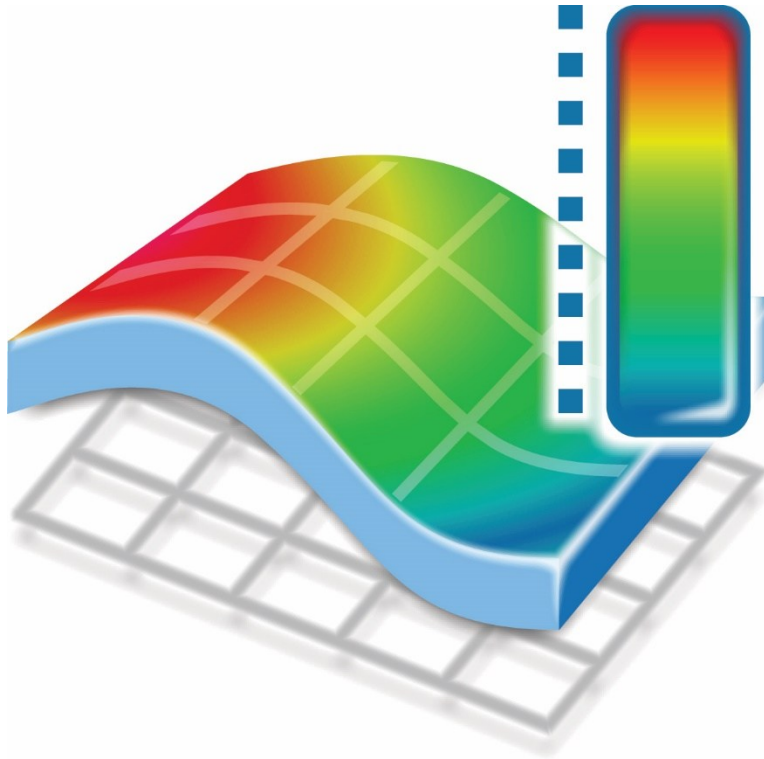




SURFACE ANALYSIS



USER MANUAL

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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 9.1.

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 (phase images) 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
- **Part Tracking** allows for the automatic tracking and cropping of same sized parts across many files
- **Creating Artificial Displacements** allows for the creation of artificial displacement files

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 Basics and Context Menus

Surface Analysis 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.

2.1 Akrometrix File Types

Akrometrix has two file formats to store data captured from TherMoiré measurement systems, phase images (*.akx_phase) and displacement files (*.akx_disp). These container files store raw data from the measurement, including intensity images, phase data (if applicable), displacement data (if applicable), and metadata associated with the measurement system and settings.

Phase image files contain 3 main components: intensity images, a phase image, and associated metadata. These files are created exclusively from the shadow moiré measurement technique

Displacement files contain a matrix of z values that correspond to the pixels in the measurement image (otherwise known as a point cloud), intensity images, and associated metadata. These files will also contain the phase image from their parent phase file, if derived from shadow moiré phase images.

2.2 Loading Measurement Data

Once the **Surface Analysis** program starts, a GUI (Graphical User Interface) frame with a grey background 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.

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 and displacement files can also be dragged and dropped into the Surface Analysis program to open them. Data windows that only exist in memory (duplicates or extracted partitions) can be renamed by right-clicking on the title bar and selecting **Rename Window...**

As of Studio 9.1, phase and displacement files are unified in a single window in **Surface Analysis**. Data windows take on a tabbed form as shown in **Figure 2.1** and **Figure 2.2**, with each tab showing a different view of the data file contents.



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

2.2.1 Resizing and zooming in on a measurement window

The data file 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+-** or scrolling with the mouse wheel. Each action adds or subtracts 20% to the current magnification level and can be reset to fit content to window by **Ctrl+0**. The data contents can be set to scale with the window size by selecting **Fit to Window** in the **Display** context menu.

2.2.2 Data Information

When a phase or displacement data file is opened in **Surface Analysis**, the image size, grayscale bit depth, magnification percentage, and cursor position data are shown on the status bar located at the bottom of the image (**Figure 2.1** and **Figure 2.2**).

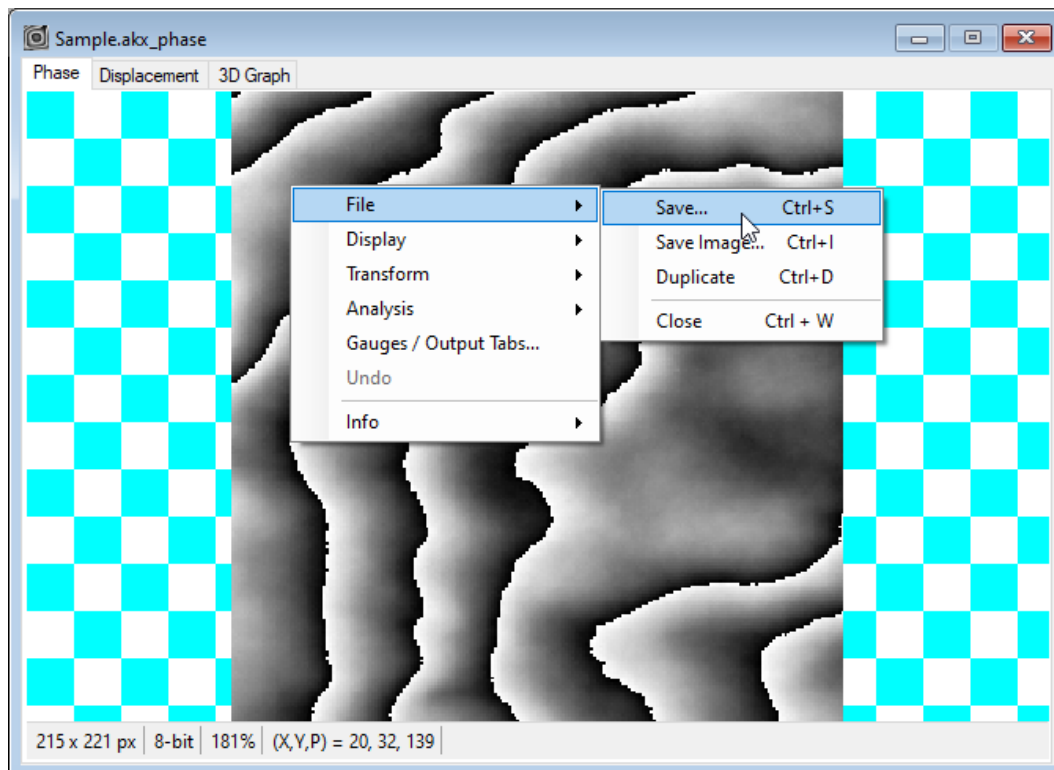


Figure 2.1 Phase File showing Phase Image

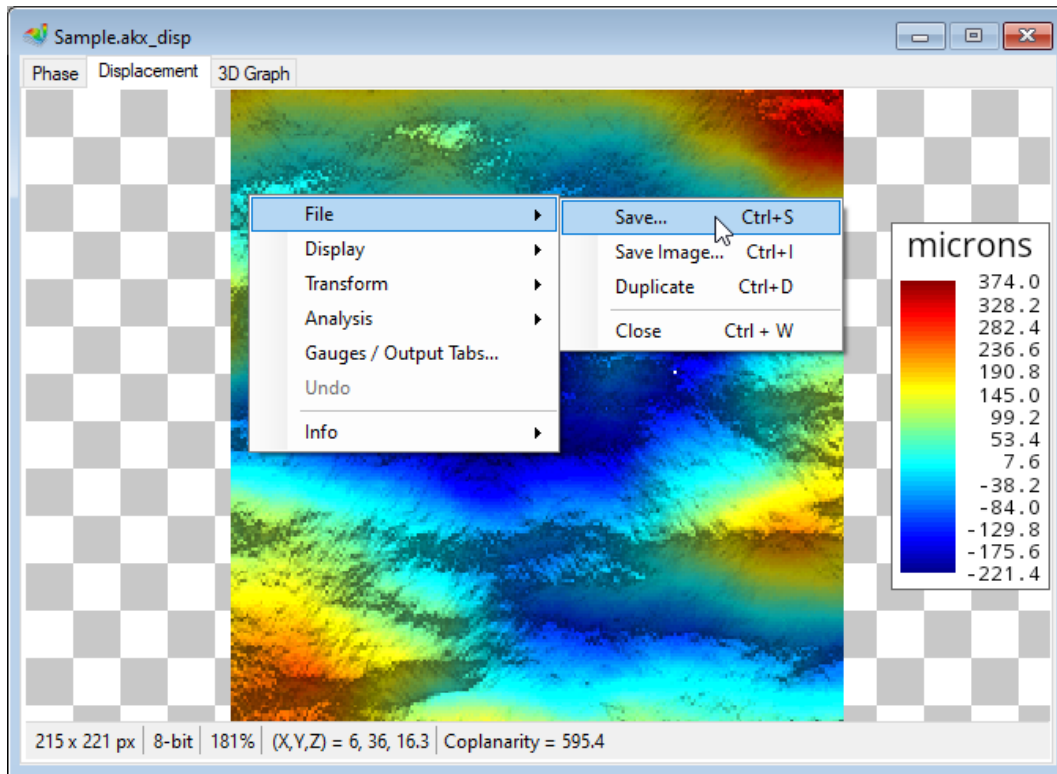


Figure 2.2 Displacement File showing Displacement Image

2.2.3 Edit Metadata

Metadata for a data file can be changed by right clicking the Phase or Displacement window and going to **Info→Edit Metadata**. For further information on metadata see **Section A.1.1**

Edit Metadata for "1_BGA0s_00002s(24C).akx_phase"											
Acq Index	Temp Setpoint	Temp Nominal	Temp Reading	Pin 1 Location	Measured Side	Interface Location	Lot Id	Operator Id	Product Id	Serial Number Id	Test Id
1	25	25	24	Upper Right	Inner	Top					20160219T163734
										Partition Full Path	Roi Name
										ProfileAcq001/1	1

Figure 2.3 Individual Edit Metadata Window

2.2.4 Measurement Information

In addition to the information described in **Section 2.2.2**, the measurement metadata can be displayed by right-clicking on the image and choosing **Info→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.

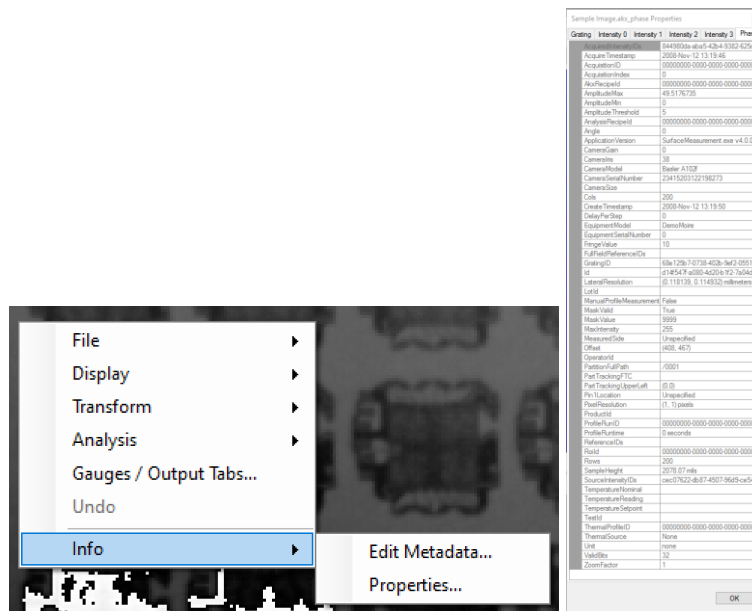


Figure 2.4 Displaying Measurement Metadata

2.2.5 Assigning Physical Size

Data captured using the Shadow Moiré technique does not necessarily include lateral resolution used to show physical dimensions on 3D plots or calculate certain gauges. Physical dimensions can therefore be assigned by the user on such data after it has been captured. Click the “Image Size” area on the status bar at the bottom left of the phase image. This can also be done by right-clicking on the image and selecting **Display→XY Size→Assign (Figure 2.5)**. In the Physical Size window that appears, 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 Physical Size pop-up window or in the main context menu **Display→XY Size→**. The selected unit will appear on the X and Y axes of all graphs created after analysis.

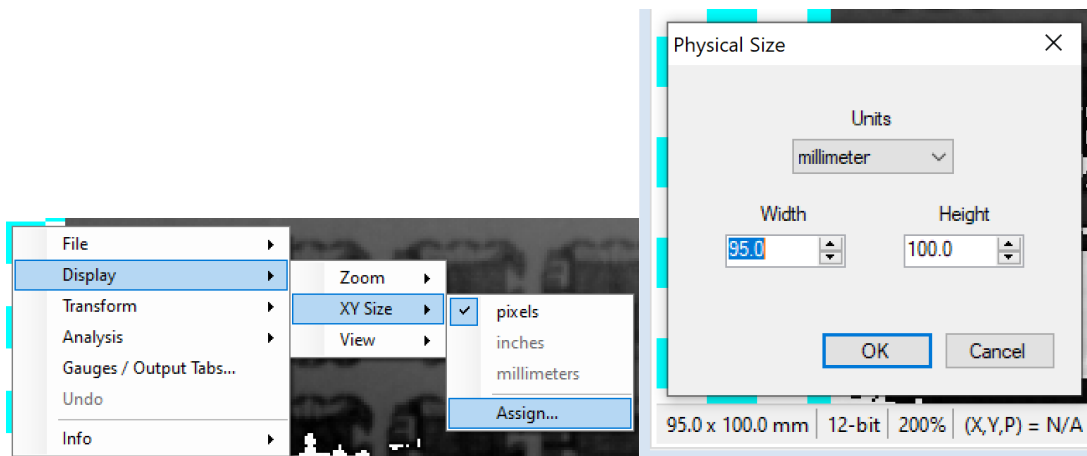


Figure 2.5 Assigning Physical Size for a Phase Image



Note: Physical dimensions are required for Compensation (**Section 4.5**) and calculation of the gauges Bow, Twist, DTA, and ROC (See **Akrometrix Optical Techniques and Analyses 101**).

2.2.6 Showing Surface or Intensity Images

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 or displacement image and selecting **Display→View→Surface (Figure 2.7)** (or, alternatively, any one of the 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 by selecting **File→Save Image...** or **Ctrl+I**.

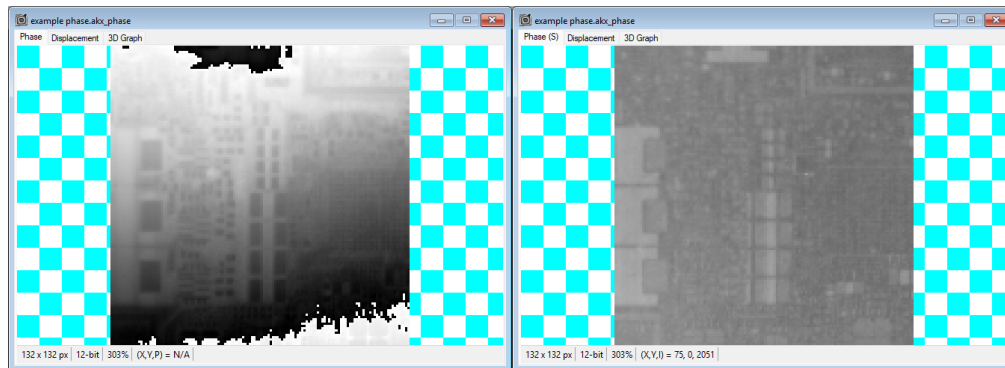


Figure 2.6 Phase and Surface Image Views

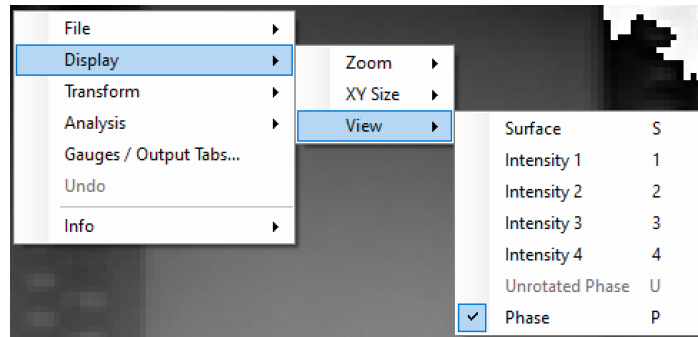


Figure 2.7 Menu Command for Showing Surface or Intensity Images

2.3 Phase Context Menu

When an *.akx_phase file is loaded in Surface Analysis, a window will open with the phase tab selected as shown in **Figure 2.1**. Commands are accessed via context menu. The organization and functions of this menu are described in the following sections.

2.3.1 File

Save...	Saves the data in *.akx_phase format
Save Image...	Allows displayed phase data to be saved as an image (*.png).
Duplicate	Makes a copy of the current data window in memory.

Close Closes the data window. Prompts to save if any changes are detected.

2.3.2 Display

Zoom Zoom in, Zoom out, Zoom to 100%, Fit To Window, and Reset Window. These commands change the content/window size.

XY Size Allows the X and Y data dimensions to be mapped to physical dimensions in either mm or inches. See **Section 2.2.5**.

View Allows for the display of Phase, Surface, and Intensity images. See **Section 2.2.6**.

2.3.3 Transform

Smooth Allows the user to apply a smooth function to the phase data. Can be repeated multiple times. See **AOTA101** for more information.

Mask Allows the data to be masked. See **Section 3.1**.

Rotate Allows the data to be rotated about its Z-axis as in **Section 3.5**.

Shift... Allows the data to be shifted in its plane as in **Section 3.6**.

2.3.4 Analysis

Partition Allows cropping into smaller and/or multiple sub-regions. See **Section 3.3**.

Unwrapping Parameters Allows custom unwrapping parameters. See **Section 4.6**.

Plane Rotation Setting Allows the displacement data reference plane to be set. See **Section 4.3**

Grating Compensation Allows the Grating Compensation function to be enabled. See **Section 4.5**.

2.3.5 Undo

Allows the user to undo the most recent changes displayed in order of application to the data.

2.3.6 Info

Allows the user to edit metadata (**Figure 2.8**) and access the properties window associated with the data. 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.

Edit Metadata for "100Meas_0001_00010g(20C).akx_phase"

Acq Index	Temp Setpoint	Temp Nominal	Temp Reading	Pin 1 Location	Measured Side	Interface Location	Lot Id	Operator Id	Product Id	Serial Number Id	Test Id	Partition Full Path	Roi Name
3	0	0	20	Upper Left	Unspecified	Unspecified					100Meas	ProfileAcq003/0001	0001

OK Cancel

Figure 2.8 Edit Metadata Dialog on Individual Phase Image

2.4 Displacement Context Menu

When an *.akx_disp image is loaded in Surface Analysis, or the phase image is analyzed by switching to the Displacement tab, a data file will open with the displacement tab selected as shown in **Figure 2.2**.

This window shows the phase data (if taken with Shadow Moire), displacement data, 3D graph, and chord plots (if selected) on one tabbed interface. Commands are accessed via context menu, just as with phase data.

Some functions overlap with those of the phase image tab and are rearranged in the context menu to accommodate additional displacement specific commands. The organization is described in the following sections.

2.4.1 File

Save...	Saves the data in *.akx_disp format
Save Image...	Allows displayed displacement data to be saved as an image (*.png).
Duplicate	Makes a copy of the current data window in memory.
Close	Closes the data window. Prompts to save if any changes are detected.

2.4.2 Display

Zoom	Zoom in, Zoom out, Zoom to 100%, Fit To Window, and Reset Window. These commands change the content/window size.
Z-Legend	Show/Hide the Z-scale legend at the right of the displacement window.
Z-Scale	Allows the Z-scale units and min/max values to be adjusted.
XY Size	Allows the X and Y data dimensions to be mapped to physical dimensions in either mm or inches. See Section 2.2.5 .
View	Allows for the display of Phase, Surface, and Intensity images. See Section 2.2.6 .

2.4.3 Transform

Detect Features	Searches for repetitive shapes in the displacement data for masking or extraction. See Section 3.9 .
------------------------	---

Mask	Allows the data to be masked. Contains all the same functions as described for phase images in Section 3.1 , with the addition of “Z-Range...”, which is unique to displacement data and described in Section 3.10 .
Smooth	Applies the default or custom smooth function to the displacement data. See AOTA101 for more information.
Plane Rotation	Applies the selected reference plane to rotate the data. See Section 4.3 .
Fit Data...	Opens a dialog (Figure 2.9) where a polynomial fit can be calculated. Alternatively, if physical dimensions are assigned, a spherical fit can be calculated.
Subtract	Calculates and displays the absolute difference between the displacement data of two displacement files. See Section 4.4 .
Rotate	Allows the data to be rotated about its Z-axis as in Section 3.5 .
Fill Holes...	Allows holes in the surface to be filled in with interpolated (artificial) data. See Section 3.6 .
Shift...	Allows the data to be shifted in its plane as in Section 3.6 .
Invert	Inverts Z data

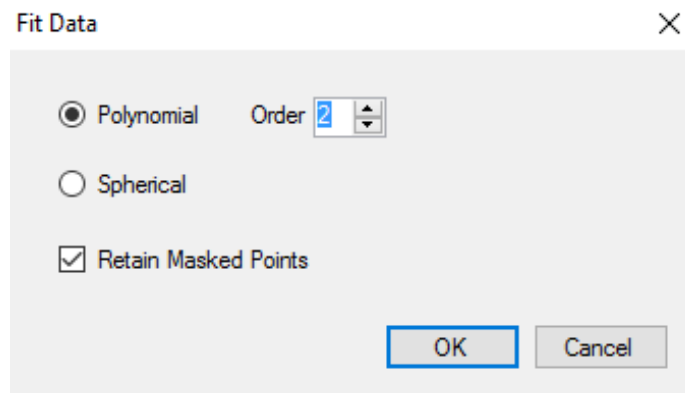


Figure 2.9 Fit Data Dialog

2.4.4 Analysis

Partition	Shows the same commands as under the Analysis→Partition menu for phase images, except for Array. See Section 3.2 .
Step Height	Allows the user to define two ROIs and calculate the height difference between them. See Section 4.7 .

- Chord** Allows for the placement of custom or predefined chords. See **Section 5.5**.
- Interface Analysis** Brings up a list of open *.akx_disp images for showing surface on surface plots from Interface Analysis. See **Section 6.3**
- SOFC...** Displays a window containing all Second Order Fit Coefficients used to calculate a 2nd order polynomial fit for the surface. This list also includes the coefficient of determination, denoted R² (R squared).

2.4.5 Undo

Allows the user to undo the most recent changes displayed in order of application to the data.

2.4.6 Info

Allows the user to edit metadata and access the properties window associated with the data. 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.

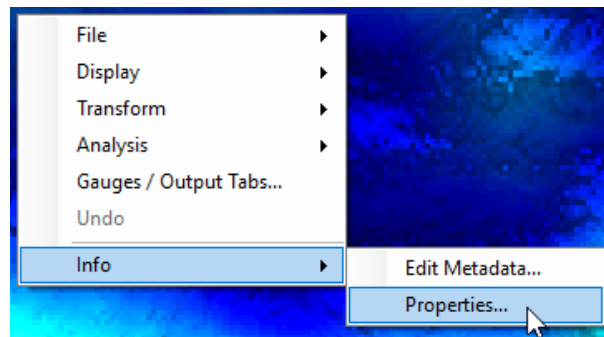


Figure 2.10 Info Menu on Displacement Image

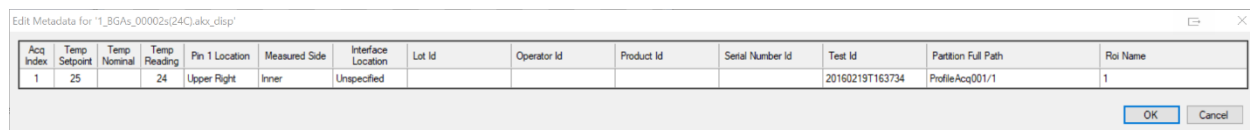


Figure 2.11 Edit Metadata Dialog on Individual Displacement Image

2.5 Saving Phase or Displacement Files

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

3 Modifying Measurement Data

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

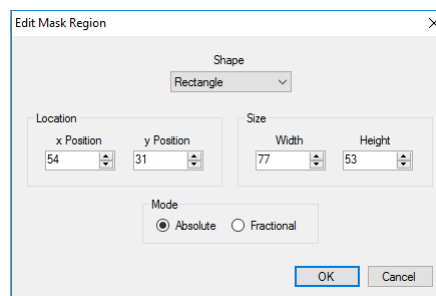


Figure 3.2 Edit ROI Region Size and Position

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.

3.1 Masking

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.

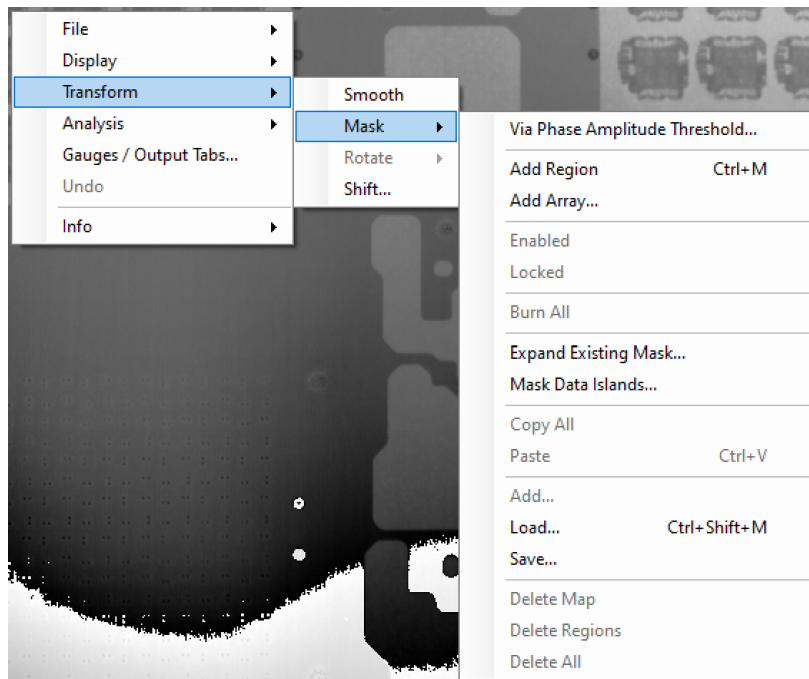


Figure 3.3 Mask Menu

3.1.1 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 **Transform→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 **Transform→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 **Transform→Mask→Enabled**. Alternating this command will turn the current mask(s) on and off. This is useful when evaluating masks between phase image, displacement 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 **Transform→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 3.1.5**).

3.1.2 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 **Transform→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.

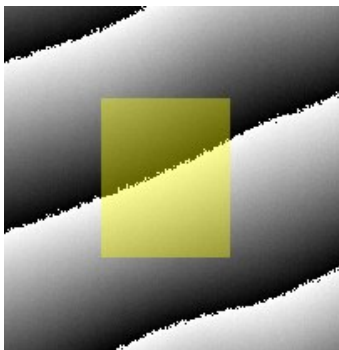


Figure 3.4 Loaded Image Mask in Yellow

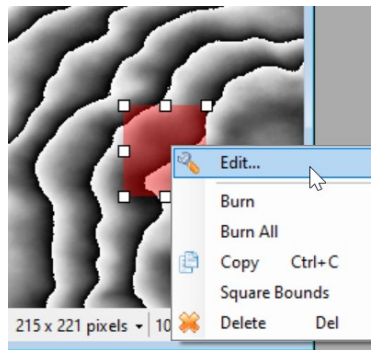


Figure 3.5 Loaded Annotation Mask in Red

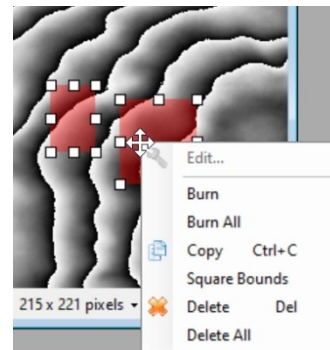


Figure 3.6 Multiple Annotation Masks Selected using Ctrl modifier key

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

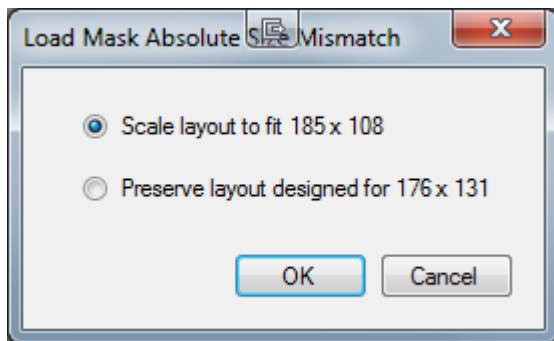


Figure 3.7 Load Annotation Mask Mismatched Size Dialog

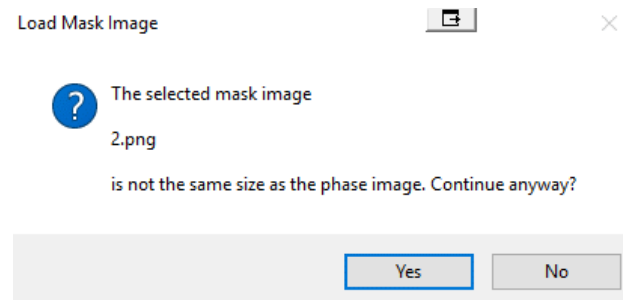


Figure 3.8 Load Image Mask Mismatched Size Dialog

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.

3.1.3 Copying and Pasting Masks

All masks on a phase image can be copied by going to **Transform→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.

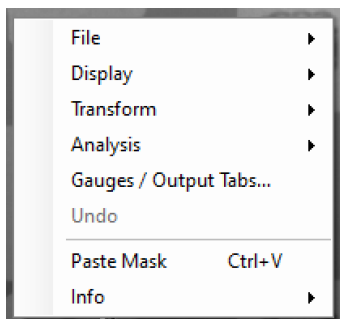


Figure 3.9 Paste Mask Option in Phase Image Context Menu



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.

3.1.4 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 **Transform→Mask→Burn All**.

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

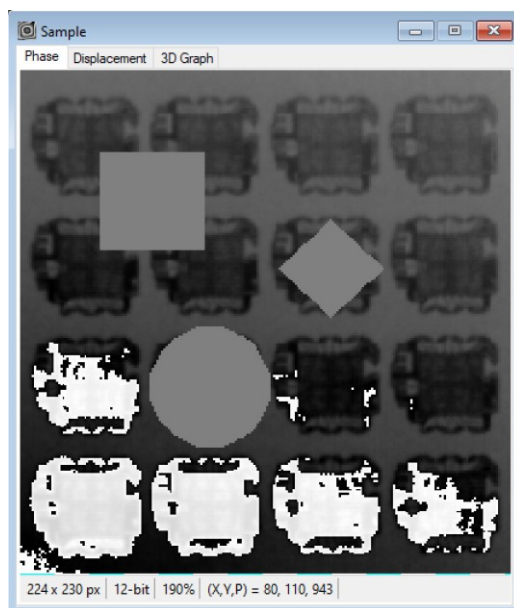


Figure 3.10 Burned Mask Areas

3.1.5 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.

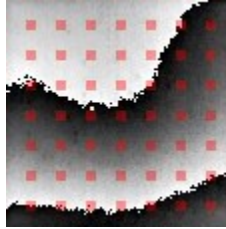


Figure 3.11 Example of a Mask Array

1. To create a new array right click in the selected phase image and choose **Transform→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.

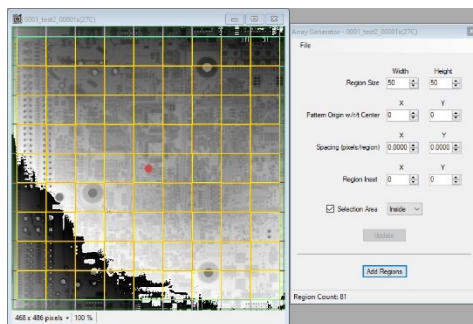


Figure 3.12 Mask Array Pattern and Parameters Window

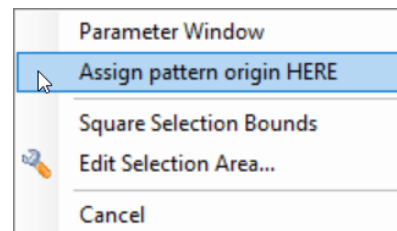


Figure 3.13 Array Context Menu

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 3.1.1**).

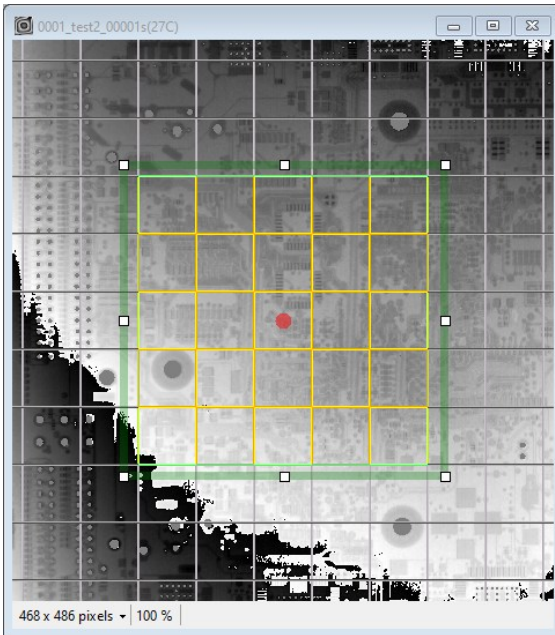


Figure 3.14 Mask Array Green Bounding Box

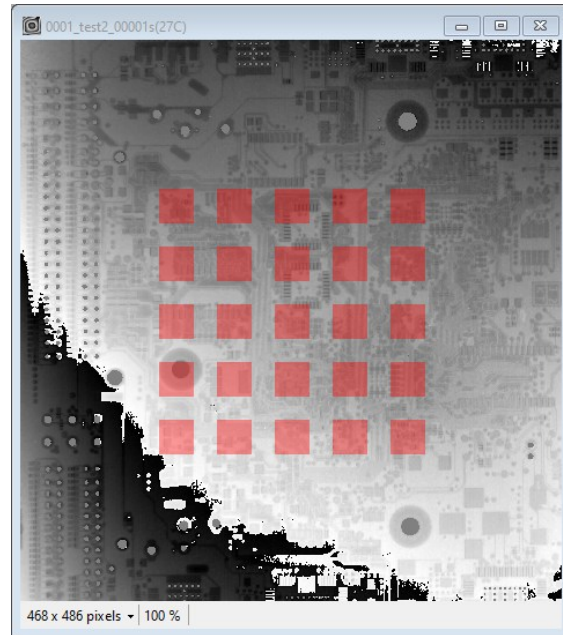


Figure 3.15 Added Mask Array

3.1.6 Expand Existing Mask

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 **Transform→Mask→Expand Existing Mask...**

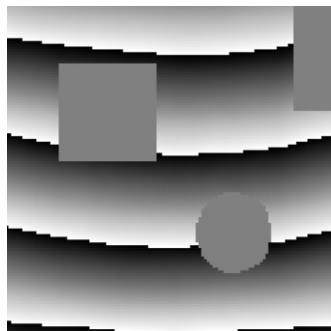


Figure 3.16 Before Expanding Existing Mask

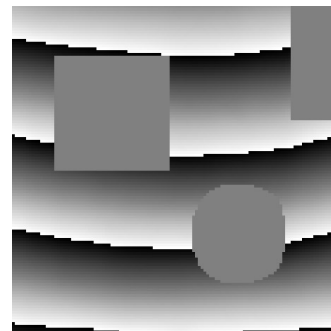


Figure 3.17 After Expanding Existing Mask

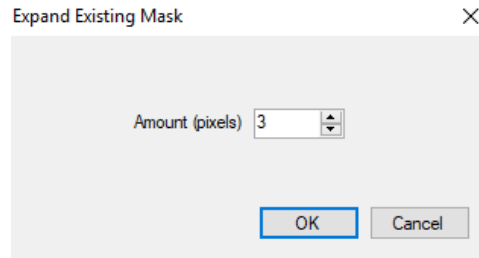


Figure 3.18 Expand Existing Mask

3.1.7 Mask Data Islands

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 **Transform→Mask→Mask Data Islands....** The user then enters a pixel size of the largest island to be masked.

3.2 Phase Amplitude Thresholding

Phase Amplitude Threshold (PAT) is used to mask data after it has been saved by Surface Measurement. This works by comparing the change in intensity per pixel used to build phase or displacement 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.

To adjust the Phase Amplitude Threshold, right click on the phase or displacement data and select the **Transform→Mask→Via Phase Amplitude Threshold...** menu option. A dialog will pop up asking the user if 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.

Unlike phase data, displacement data can only be removed, not recovered.

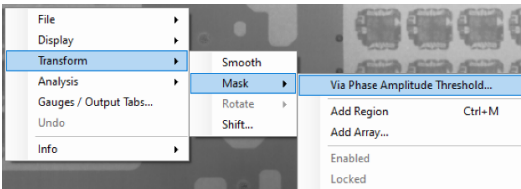


Figure 3.19 Amplitude Threshold Menu Option

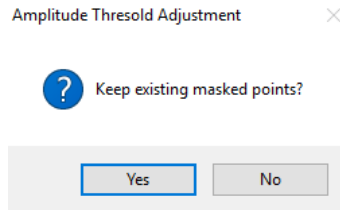


Figure 3.20 PAT Keep Existing Masked Points?

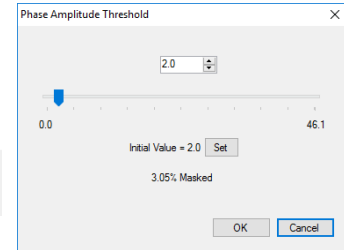


Figure 3.21 Phase Amplitude Thresholding Adjustment Window

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

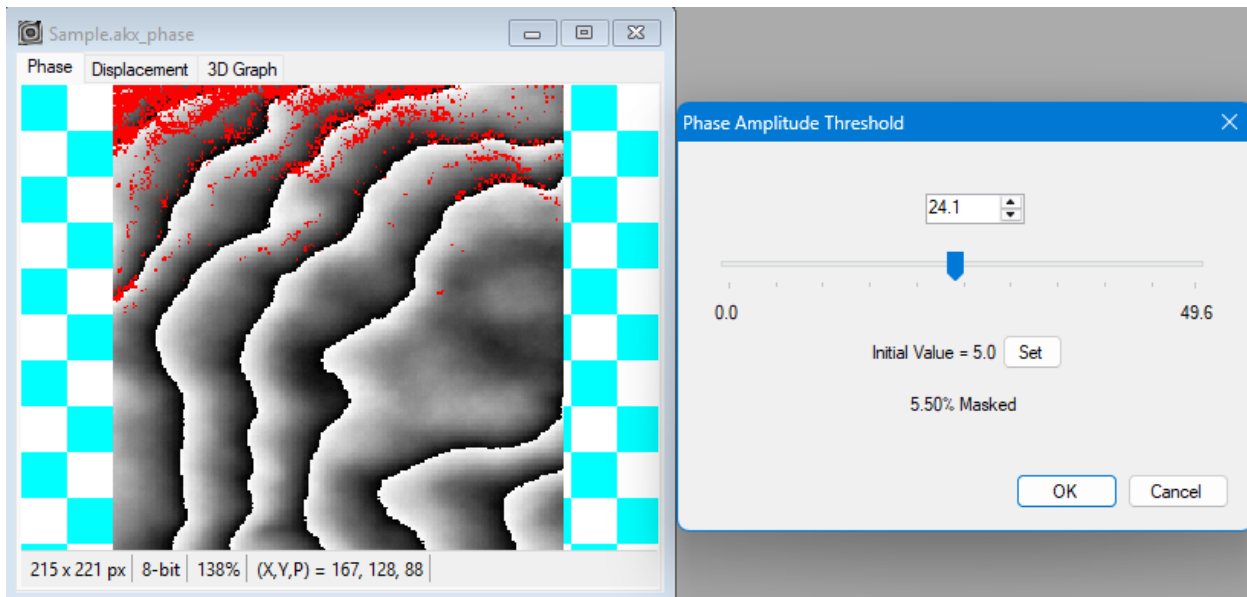


Figure 3.22 Phase Amplitude Thresholding

As the slider is adjusted, masked areas will be highlighted red on phase data or white in displacement data. To go back to the original PAT value, click the Set button. Hit OK to apply the mask to the data.



Note: Dragging the slider quickly or large distances may cause some delay in recalculating mask areas. This is particularly true with large data sets 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 data is being processed.

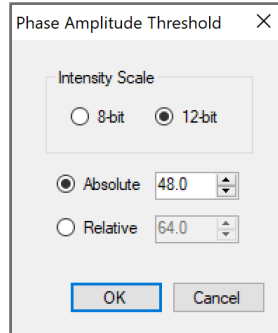


Figure 3.23 Phase Amplitude Threshold Batch Dialog

3.3 Partitioning a Data File

Partitioning is a function where one or more ROIs are cropped from a phase or displacement file while leaving the original data intact. This function is useful for measuring multiple samples in a single run and later extracting the individual samples from a much larger data set. The same partition can be applied to multiple data files using the Batch Cropping tool described in **Section 7**.

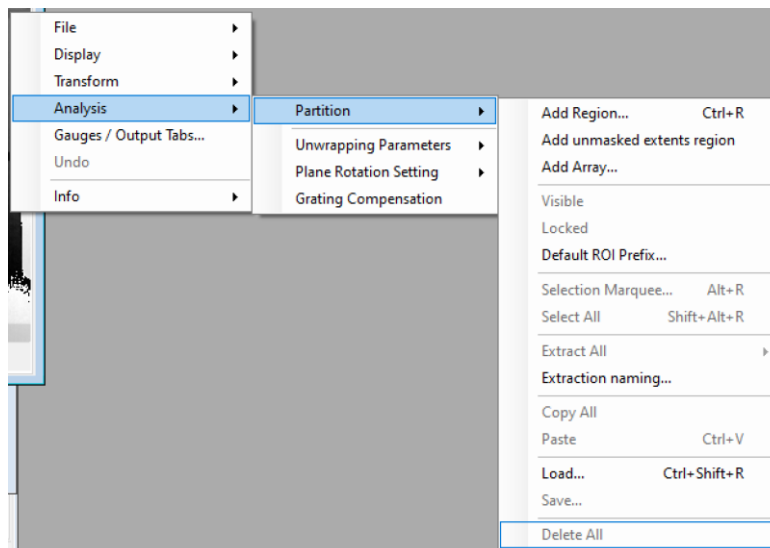


Figure 3.24 Partition Menu

3.3.1 Creating a Partition

1. To create a new partition, right-click in the selected data and choose **Analysis→Partition→Add Region...** (or **Ctrl+R**).
2. To create the first region in the new partition, draw a rectangle on the data file with the mouse.
3. A cyan ROI appears and all the ROI commands described in **Section 3.1** apply to the partition ROI. By default, the regions will be named "0001", "0002", etc, but the default can be changed by going to **Analysis→Partition→Default ROI Prefix...** Previously used ROI names will be saved in a list for recall later.

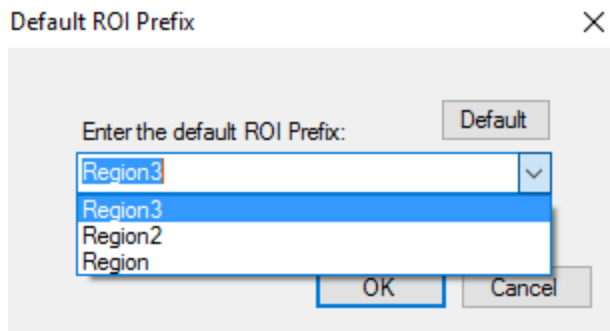


Figure 3.25 Default ROI Prefix Dialog

- Right-clicking inside any ROI and choosing **Edit...** allows the region name to be changed as well as the Shape, Location, Size, and whether the units are absolute or Fractional (**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/displacement data. The size is relative to the full x and y dimension of the data.

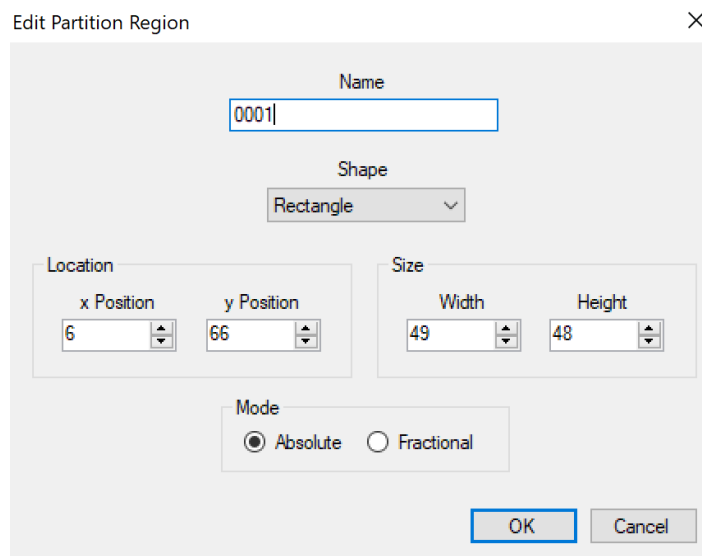


Figure 3.26 A Partition ROI Properties Window

- Additional regions can be added to the partition (**Figure 3.27**) by repeating steps 1 through 3. Regions may overlap.

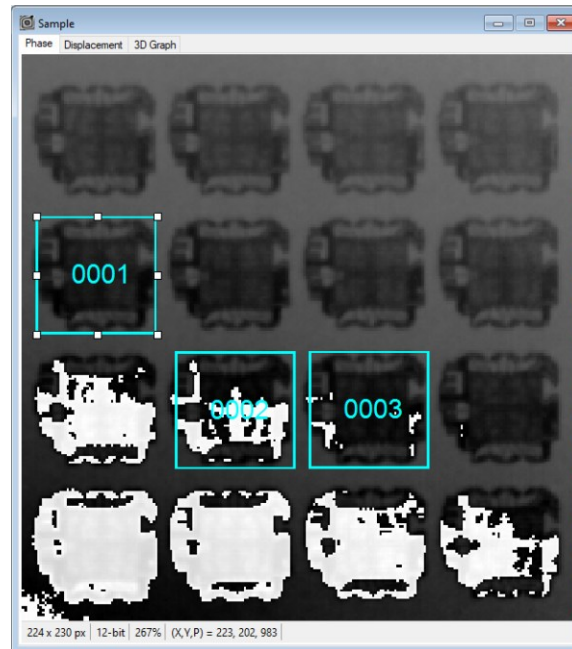


Figure 3.27 Multiple Regions on One Phase Image

6. When the partition is complete, it can be saved to a file (*.akx_partition) by right-clicking inside the phase/displacement data (but not inside a region) and choosing **Analysis→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 on the data (but not inside a region) and choosing **Analysis→Partition→Delete All.**
8. The partition can be locked by going to **Analysis→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 3.3.5**).
9. The partition can be made visible or invisible by going to **Analysis→Partition→Visible.**

3.3.2 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 **Analysis→Partition→Load...** (or use the keyboard shortcut, **Ctrl+Shift+M**), and select the desired partition file.

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

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



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

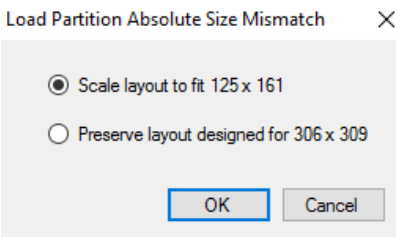


Figure 3.28 Load Partition Absolute Size Mismatch

Scale layout will use the fractional values from the mask relative to the original data 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 data bounds will be loaded.

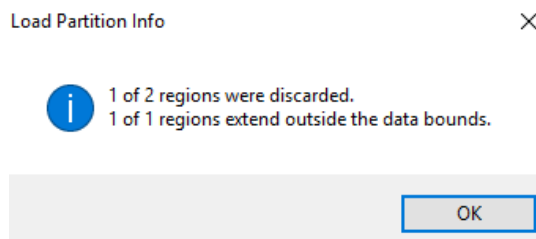


Figure 3.29 Load Partition Preserve Layout Info

3.3.3 Copying and Pasting Partition Regions

A mask can be copied by going to **Analysis→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 data, and go to **Paste Partition Region**. When the target data has focus, the shortcut **Ctrl+V** also works for this function.

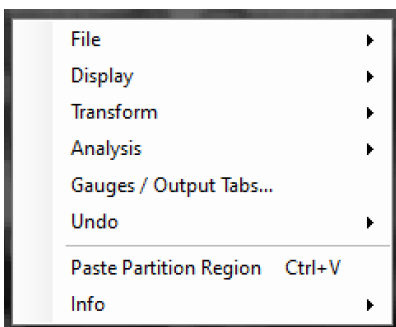


Figure 3.30 Paste Partition Region Option in Phase Image Context Menu



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

3.3.4 Extracting Regions

Partitions can be extracted from the original data file, either to new windows (**Figure 3.31**) or to independent data files saved to disk. To extract a region as a new data file, right-click inside the region and choose **Extract**, then choose between **'to window'** and **'to file...'** (**Figure 3.32**). To extract all regions 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 **Analysis→Partition→Extraction Naming**. The options given are to prepend the ROI name to the parent file name, append the ROI name to the parent file name or just the ROI name. The default file names can be edited when extracting individual partitions to files, but are used automatically when **Extract All→'to files...'** is chosen.

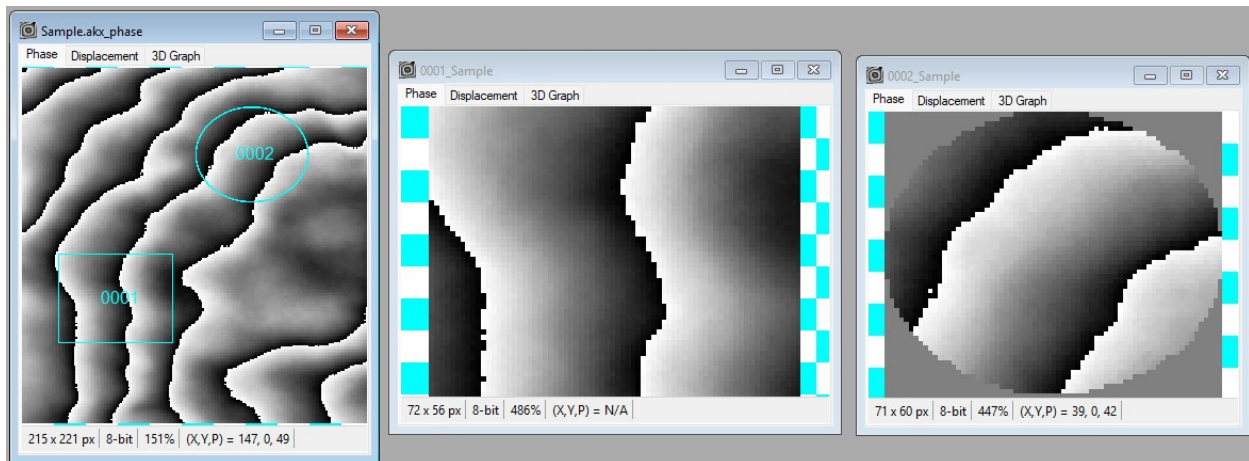


Figure 3.31 Extracted Regions from a Phase Image

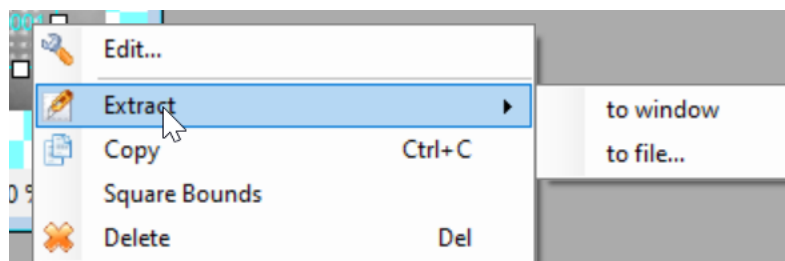


Figure 3.32 Partition Context Menu - Extract

3.3.5 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 or displacement file and choose **Analysis→Partition→Add Array...**
2. A checkerboard pattern representing where partition regions will be placed appears on the data. 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.
5. The array pattern origin can be changed graphically by right clicking at the desired point on the data and selecting **Assign pattern origin HERE** (**Figure 3.35**).

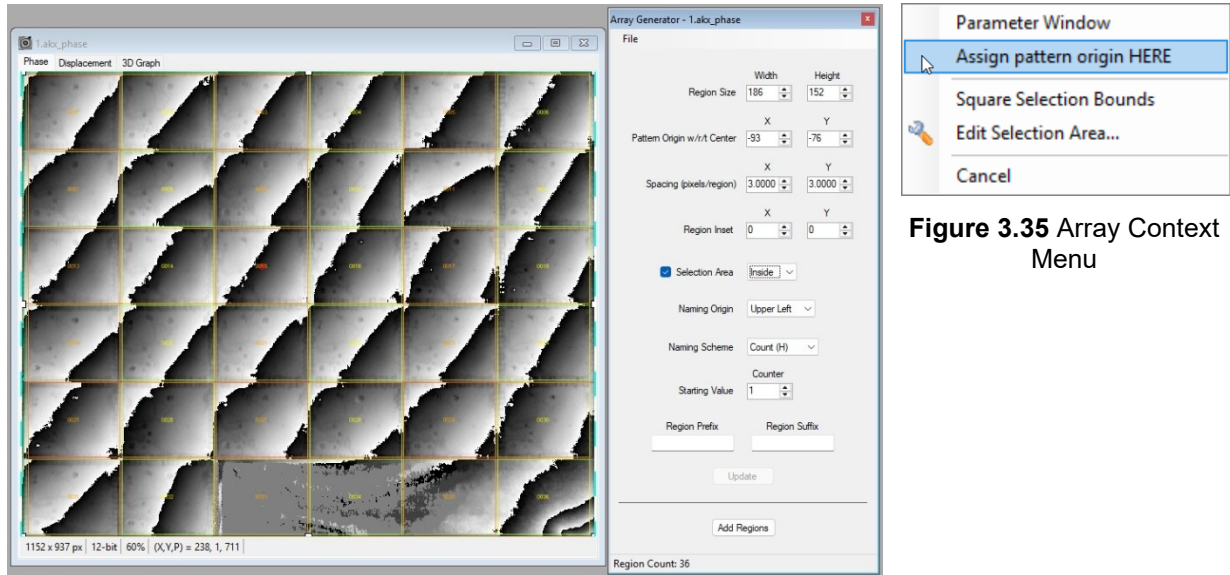


Figure 3.34 Partition Array Parameters

- 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 3.3.1**).

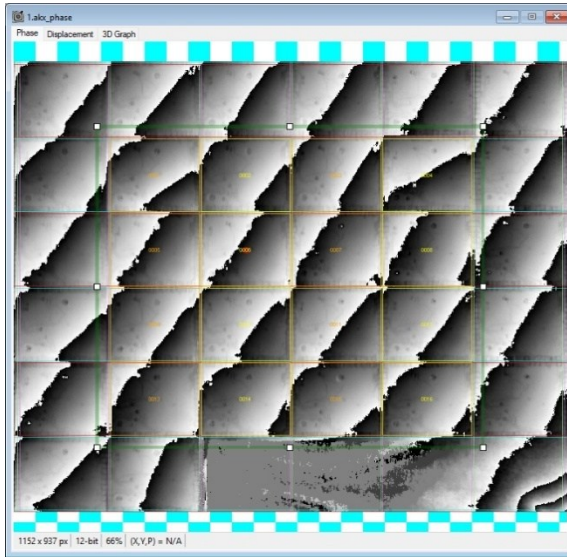


Figure 3.36 Green Array Bounding Box

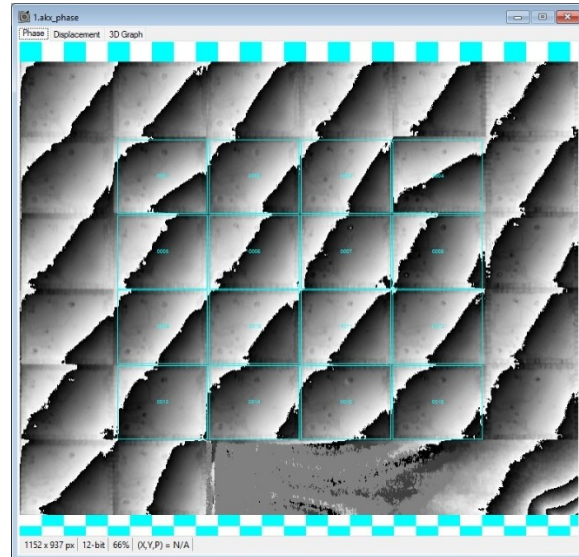


Figure 3.37 Added Partition Array

3.3.6 Add Unmasked Extents Region

The Add Unmasked Extents Region function creates a region that encompasses the furthest unmasked edges of a dataset, allowing the user to quickly crop out masked 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 dataset with an unmasked extents region already created.

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

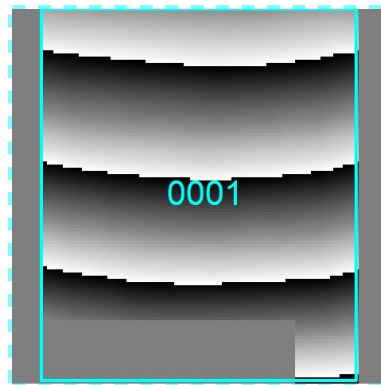


Figure 3.38 Unmasked Extents Region

3.4 Smoothing a Phase Image

The **Smooth** command applies a smoothing function to the 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. 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.

3.5 Rotating Data

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



Note: Data rotation is different from reference plane rotation that is discussed in **Section 4.3**. The former rotates the data about the Z axis while the latter changes the Z reference plane. To choose the method of rotating a reference plane, right-click on the phase image and choose **Analysis→Plane Rotation Setting** and select the desired plane rotation. (**Figure 3.40**).

To rotate data, right-click on the image, choose **Transform→Rotate** and select the desired rotation (**Figure 3.39**).

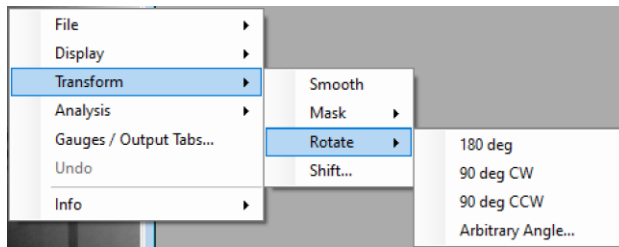


Figure 3.39 Phase Image Rotation

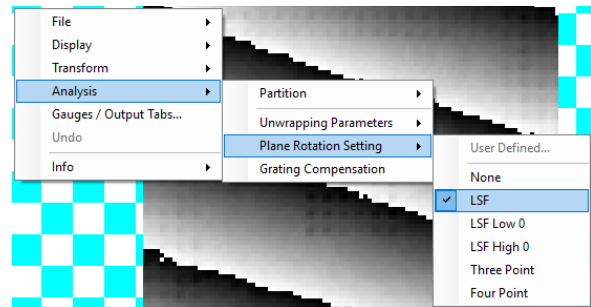


Figure 3.40 Plane Rotation Setting



Note: Rotation is disabled when Step Heights, Chords, Masks, or Partition regions are defined to prevent unwanted behavior upon analysis, mask burning, or extraction.

3.6 Fill Holes

As of Studio 9.1, holes in displacement data can be filled via an interpolation function. The interpolation polynomial order can be chosen, as well as the maximum pixel size of the holes to be filled. Optionally, a custom smooth operation can be performed after the holes are filled. This smooth function has all the same options as in the standalone Custom Smooth function discussed in **AOTA101**.

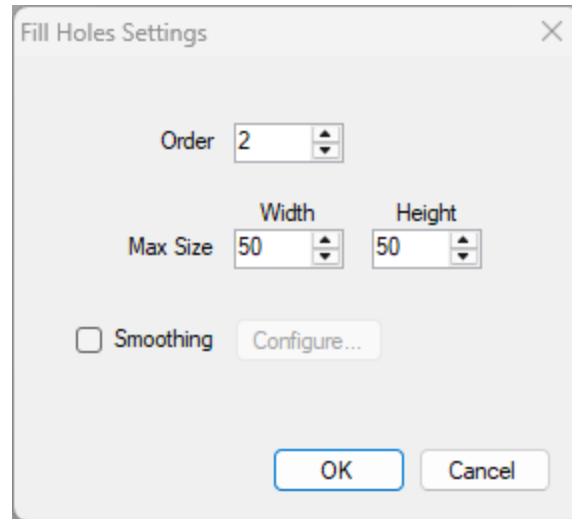


Figure 3.41 Fill Holes Dialog

3.7 Shifting Data

Shifting data moves it beyond the original pixel dimensions and fills in mask data from where it shifted. It is useful when a sample does not have the desired position in the original data (e.g. a part has shifted to one side of the sample support fixture during a temperature profile).

To shift a data set, right-click on it and choose **Transform→Shift...** and select the desired shift in either the X (left-right) or Y (up-down) direction. The data will shift with respect to an origin that is defined as the top left of the phase image (see Figure 3.42).

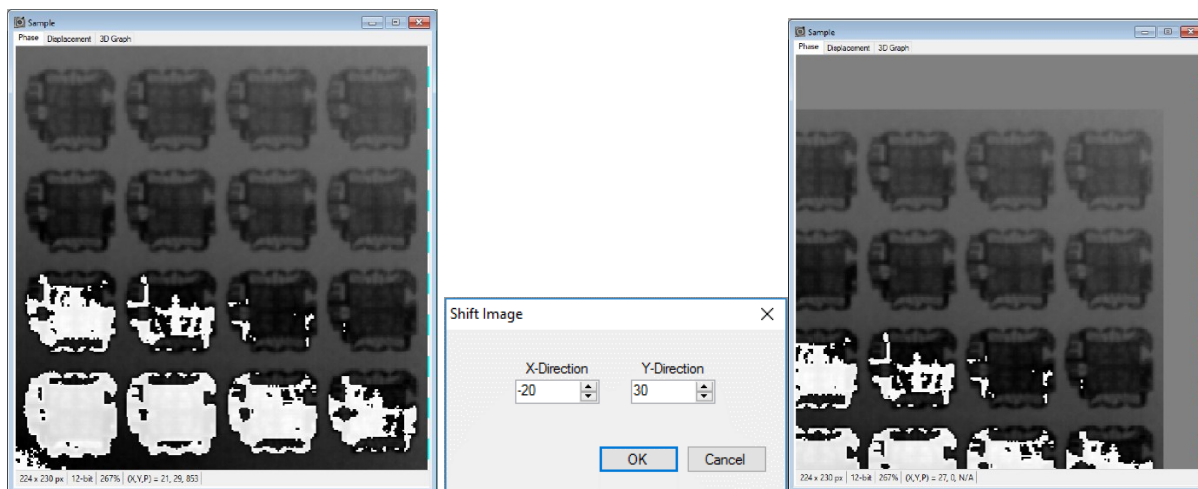


Figure 3.42 Shifting a Phase Image

3.8 Undoing Data Modification

To undo data modification from masking, partitioning, smoothing, rotating or shifting, right-click and select **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

data back one operation. Clicking on any item in the middle of the list will remove all the actions from the top to this item.

3.9 Feature Detection

Feature Detection allows masking or extraction of repetitive shapes 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 3.43**) and the Feature Detection window (**Figure 3.44**). While the Feature Detection mode is active, tab switching in the displacement data window is disabled. This mode can be turned off by pressing **Esc** or selecting Cancel from the context menu.

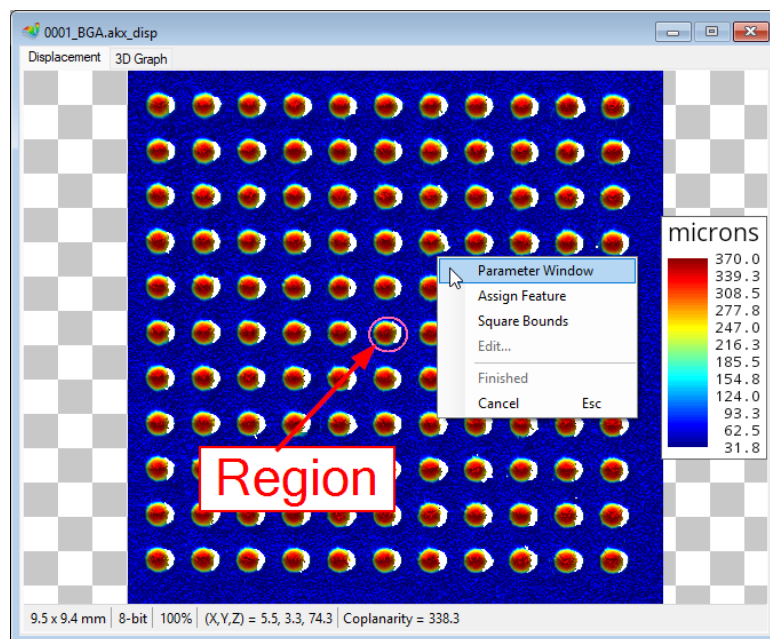


Figure 3.43 Feature Detection Region

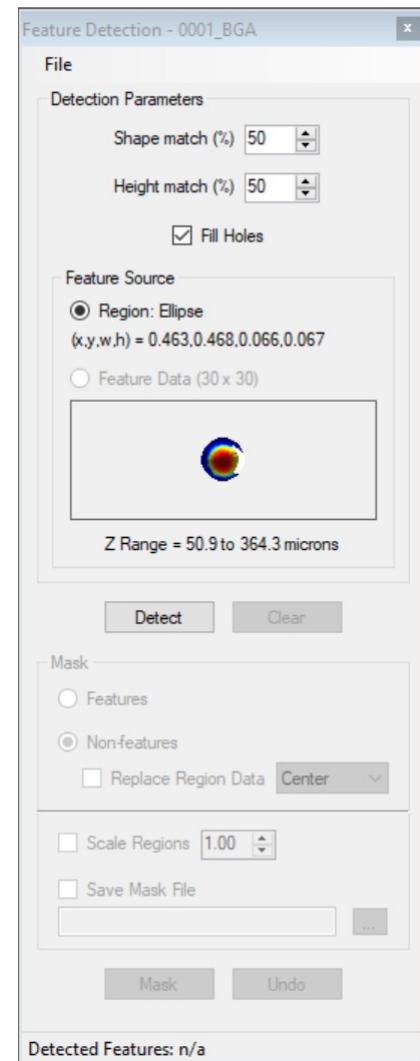


Figure 3.44 Feature Detection Parameter Window

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 match the target 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 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 3.45** and **Figure 3.46**. They are mostly the same, but since the mask step can have multiple ROIs, there are more editing options.

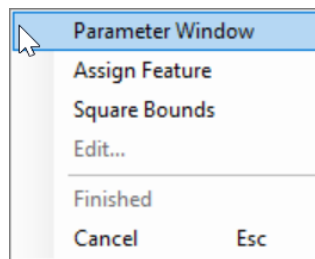


Figure 3.45 Feature Detection Context Menu - Detection

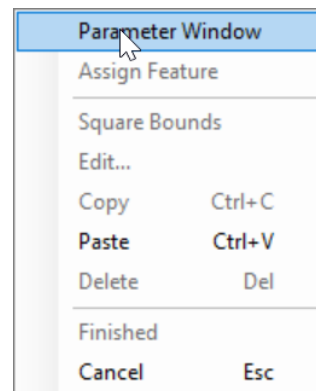


Figure 3.46 Feature Detection Context Menu - Masking

- **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 3.44**), detection parameters can be set based on the feature detection region (**Figure 3.43**). 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.

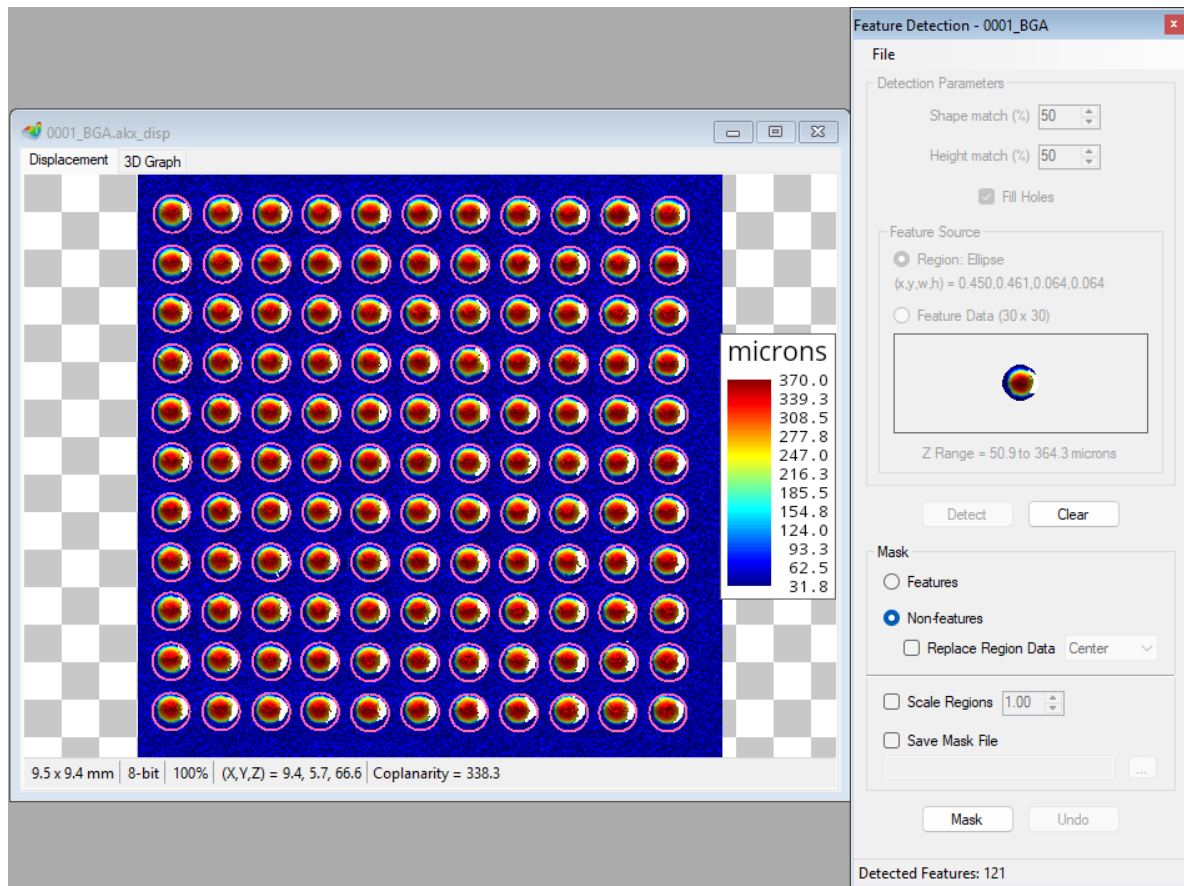


Figure 3.47 Feature Detection with Fill Holes – Solder Ball Peaks on BGA

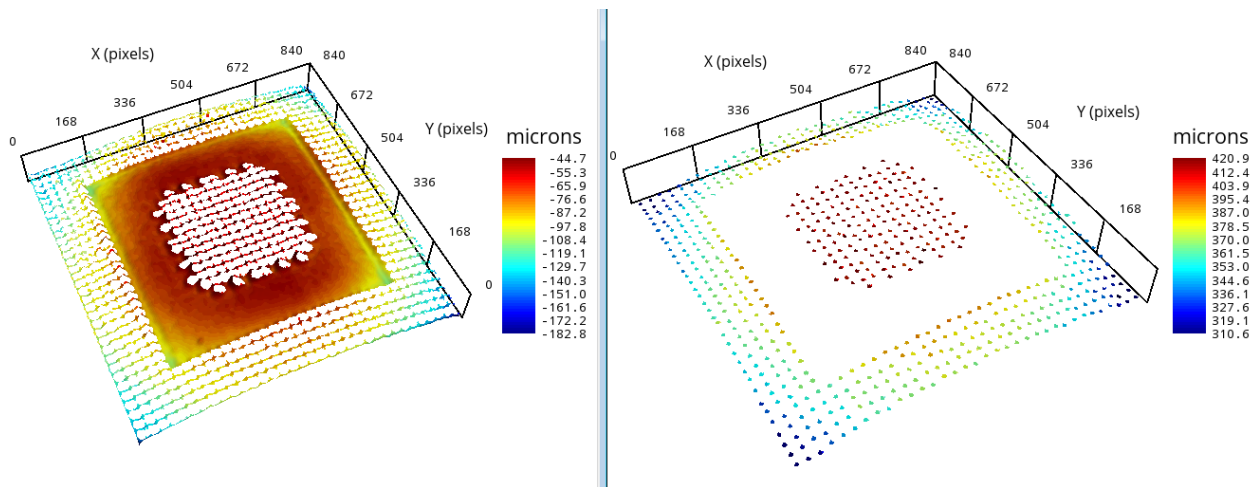


Figure 3.48 Analyzed Data with Feature Detection: Mask Feature and Mask Non-Feature

3.10 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 3.49**) and the context menu

will change to that for Z-Range Mask (**Figure 3.50**). This mode can be turned off by pressing **Esc** or selecting **Cancel** from the context menu.

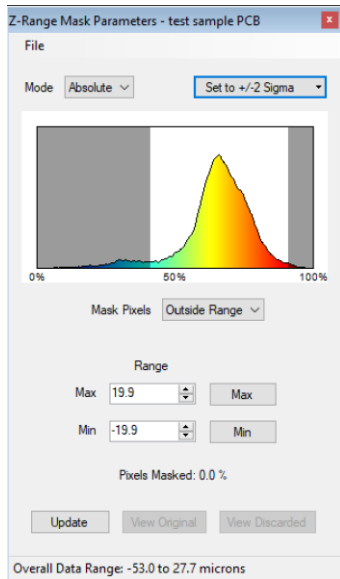


Figure 3.49 Z-Range Mask Parameters Window - Absolute

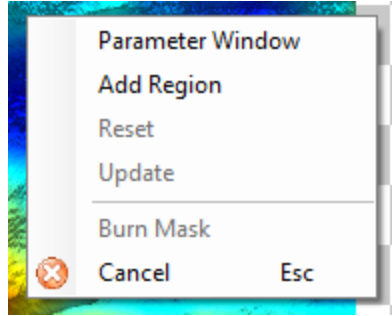


Figure 3.50 Z-Range Mask Context Menu

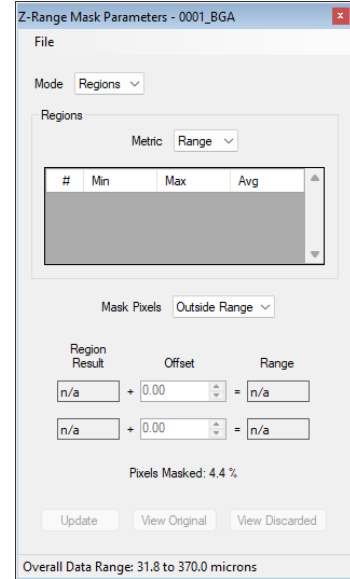


Figure 3.51 Z-Range Mask Parameters Window - Regions

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 parameters to be loaded from 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, Regions or by a $\pm 1, 2$, or 3 Sigma distribution. (**Figure 3.49**). 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 most 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. The $\pm$ Sigma Z-Range masking will filter data by the equivalent number of standard deviations of the total data range and is only displayed in the Absolute or Percent modes.

Regions Mode (**Figure 3.51**) allows data to be filtered based on values in selected regions. Once a region has been added via the context menu (**Figure 3.50**) 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 minimum is the bottom.

The bottom section of the Z-Range Parameters Window displays data relevant to the masking process and shows results. **Pixels Masked** displays the percentage of currently masked pixels and the **Overall Data Range** is shown at the bottom. **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 3.50**) 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 3.52**.

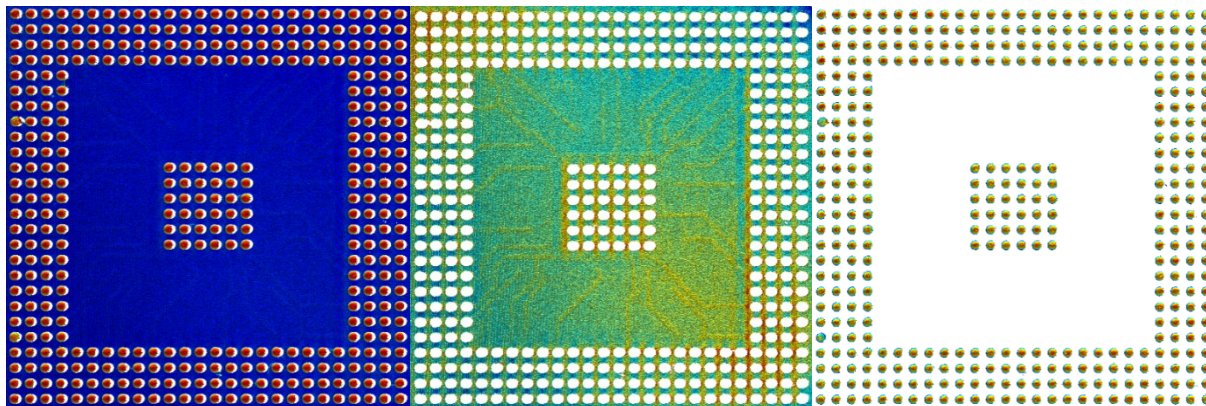


Figure 3.52 Data with High and Low Z-Range Masks

4 Analyzing Measurement Data

Analysis is the mathematical conversion of the measurement data (i.e. phase image) into displacement data (the height of the surface at each image pixel in physical units). As of Studio 9.1, analysis occurs automatically when switching off the phase tab and the result shows up in a new tab of the same unified window. Displacement files, if generated from a phase file, will now show a tab with the phase image that it was generated from. This section describes how to configure the analysis process outputs and a key factor in the analysis, the choice of reference plane. The graphical *output* options are described in **Section 5**.

4.1 Analysis

There are two methods to trigger analysis of the phase measurement data:

- A. Select any tab other than the Phase tab and analysis occurs automatically. If the Displacement or 3D Graph tabs are selected in the “Phase window initial tab” option, then analysis occurs on opening the phase image.
- B. To analyze multiple measurement data in parallel, use the **Batch Analysis** function described in **Section 7.1**.

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.

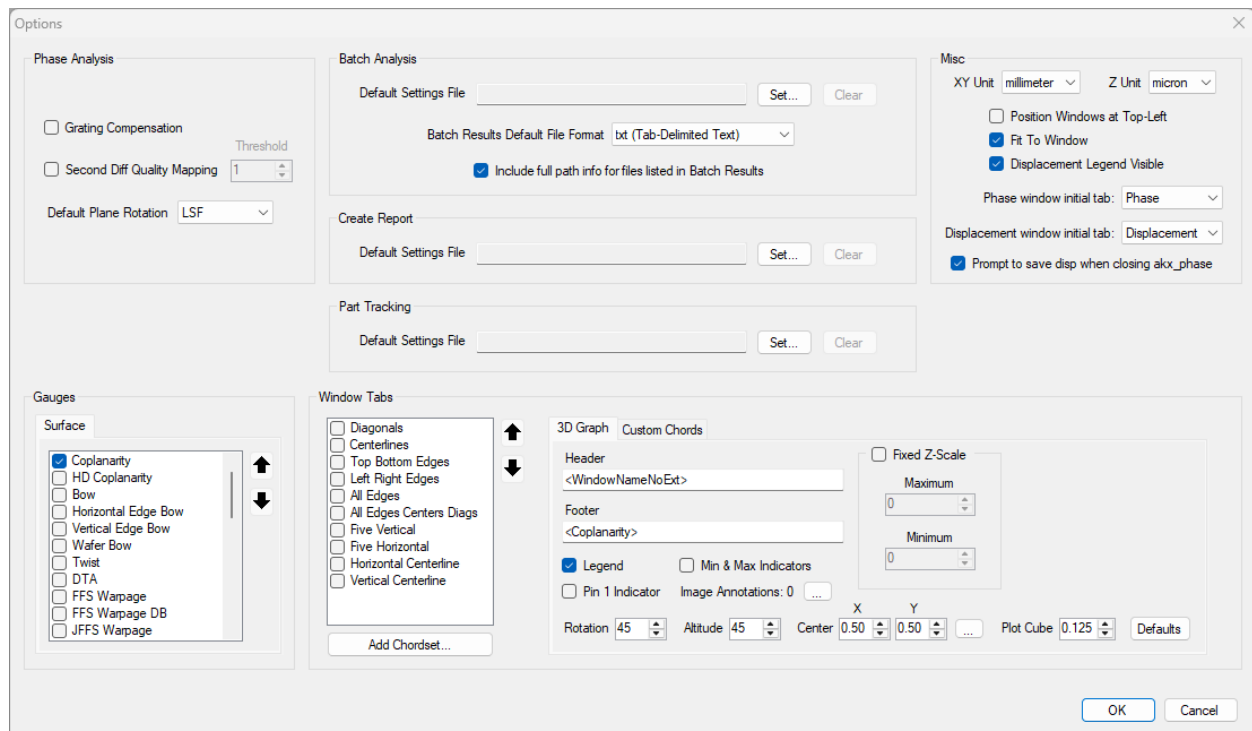


Figure 4.1 Options Window

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

XY Unit	Displays the in-plane dimensions in English (inches) or metric units (millimeters).
Z Unit	Displays the out-of-plane dimensions in English (mils, 1 mil = 0.001 inches) or metric units (microns, or μm).
Position Windows at Top-Left	Checking this box causes all files to open at the top-left corner of the Surface Analysis window. Even when multiple files are opened at the same time, they will stack on top of one another in the top-left corner.
Fit to Window	Checking this box causes files to open so that the image content fills the available space of the window. If the image is small, it will be zoomed in to fit the minimum opening window size.
Displacement Legend Visible	Checking this box causes the z unit legend at the right of the displacement tab image to be enabled or disabled.
Phase window initial tab	This drop-down menu allows the user to specify what tab or graphical output should be displayed when a phase file is initially opened.
Displacement window initial tab	This drop-down menu allows the user to specify what tab or graphical output should be displayed when a displacement file is initially opened.
Prompt to save disp when closing akx_phase	Checking this box will cause a message to appear prompting the user to save the *akx_disp file when closing a phase file. This will only appear when viewing a tab other than the Phase tab.
Batch Analysis	Allows the user to load a *.akx_recipe file to change the default Batch Analysis settings. Also allows the Batch Results 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.
Part Tracking	Only visible if a Matrox Imaging Library (MIL) key is plugged in. Allows setting a default part tracking settings file.
Grating Compensation	Checking this box applies compensation to all measurement data that contain compensation parameters (See Section 4.5 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 Analysis→Grating Compensation .

Second Diff Quality Mapping Threshold	Checking this box allows a predefined threshold to be automatically applied to each file that is opened (See Section 4.6.3 for discussion of Second Difference Quality Mapping Threshold).
Default Plane 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 at the bottom of both the Displacement and the 3D graph tabs. 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.
Window Tabs	Selects which graph formats (see Sections 5.1 through 5.5) are displayed as additional tabs in a phase or displacement window. A graph on the list may be highlighted by clicking on it once. Checking a box means that graph will be displayed as another tab in the phase or displacement file. Additionally, a tab appears to the right in which the graphical output of that graph can be configured. The up and down arrows move the highlighted graph up and down the list, changing the order in which output tabs are displayed.
3D Graph	The 3D Graph configuration tab is always available as an output and appears first. The Header and Footer information can be changed in this tab as well as other output options. The Image Annotations selection box allows the user to embed images into the 3D Graphs and alter their position and size in the 3D Graph. The Rotation, Altitude, Center, and Plot Cube values can be altered to change the default perspective the 3D Graph data is presented with. The Defaults button will reset all these parameters.
Custom Chords	The Custom Chords tab is the second default tab under the Window Tabs section. If any custom Chordset is added this tab is where the Header and Footer can be configured. The Legend can be enabled or disabled. The chord(s) can also be set to Normalize, which will rotate the chord so that the endpoints are zero. All other Window Tab types are chords and their selections will have the same options as Custom Chords.

- 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. Each graph tab in Window Tabs will have its own Fixed Z-Scale selection and range. This option is also available in Batch Analysis (**Tools→Batch Processing...→Analyze Tab** where the option is named Common Z-Scale since it is being applied to multiple outputs).
- Add Chordset...** Allows the user to upload any non-default 2D chordset to the output of all files. The 2D configuration file has an extension of *.akx_2Dconfig and is used for any 2D chords. See **Sections 5.4 and 5.5**.
- OK** Any changes to the settings are saved and the window is closed.
- Cancel** The window will close without changes to the settings.

4.3 Reference Plane – Rotation

When analyzing phase 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 Plane Rotation** pull-down list.



Note: The rotation option chosen in the Options window will be applied to all phase data when loaded and analyzed. The rotation option chosen from an individual phase or displacement file will only be applied to that particular data.

The rotation choice can also be made to any individual phase file by right-clicking and choosing **Analysis→Plane Rotation Setting (Figure 4.2)**. The resulting rotation will only be visible when switching off the Phase tab.

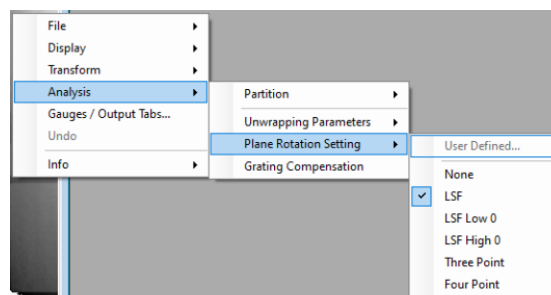


Figure 4.2 Reference Plane Rotation

For phase data, **Plane Rotation Setting** provides the following options for defining the zero reference plane:

- **None:** The analyzed 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.

On displacement data the rotation choice is in a different menu, since the data is already analyzed. It is located in the **Transform→Plane Rotation** context menu (**Figure 4.3**). When rotating displacement data, a 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.

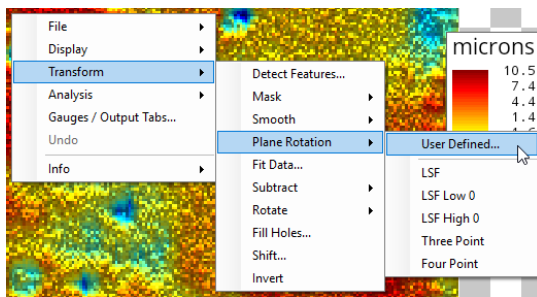


Figure 4.3 Displacement Plane Rotation Menu

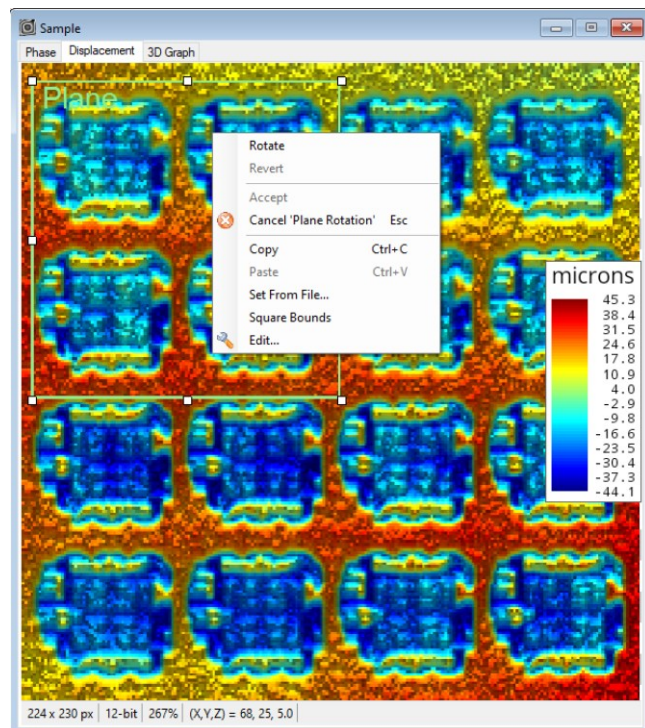


Figure 4.4 User Defined Plane Rotation Context Menu

In **Figure 4.4** 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.

Whether phase or displacement data, the height 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 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. To calculate relative displacement, first open the reference surface and any relative surfaces of interest. In the context menu of the desired relative data, **Transform→Subtract** shows a list of open surfaces where the reference can be selected.

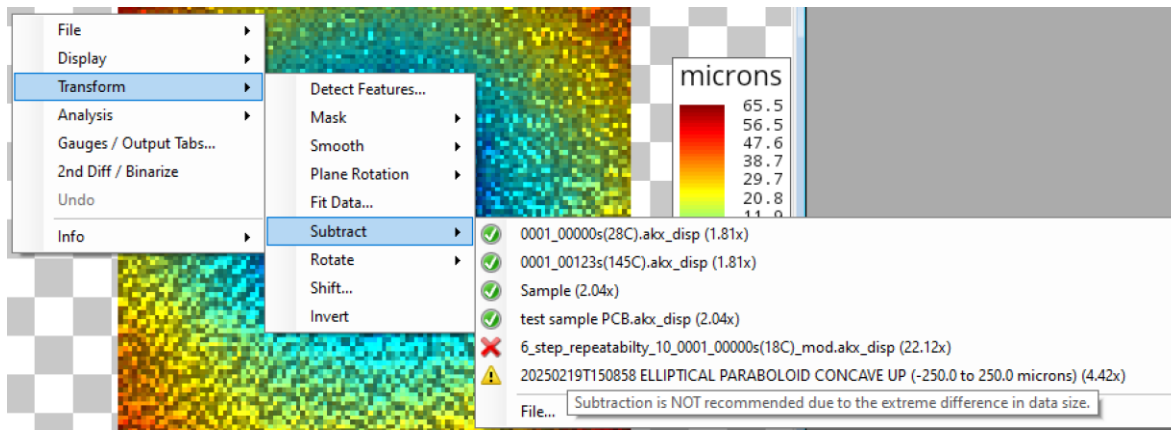


Figure 4.5 Displacement Relative Plot UI

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 of the extreme surface size difference when hovering over the file name of the surface to be subtracted in the context menu (**Figure 4.5**). Surfaces of similar dimensions are shown with a green checkmark up to a 4x difference. Surfaces with dimensions of 4x to 10x difference are shown with a yellow caution symbol and subtraction may not be ideal. Surfaces greater than 10x different are shown with a red X and subtraction is not recommended but is allowed if selected.

4.5 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 **Analysis→Grating Compensation**. To turn off compensation, repeat the process and uncheck the selection by clicking it again.



Note: In the options window, **Grating Compensation** 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 2.2.5**). 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 early 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 4.8**. Only the center is analyzed because of the mask, which stops the unwrapping process from continuing to the valid surrounding data.

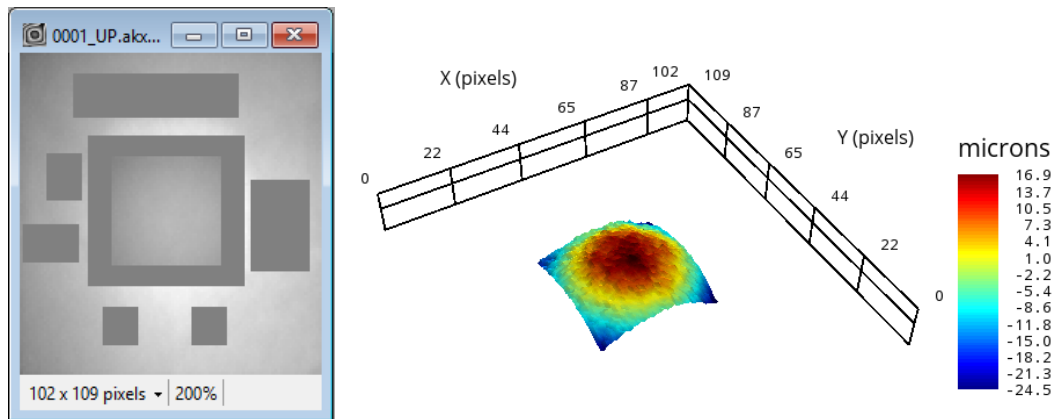


Figure 4.6 Isolated data

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 4.7** shows an example. Instead of starting in the center as in **Figure 4.6**, 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.

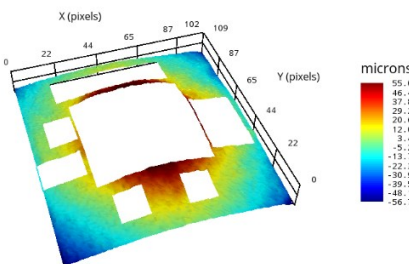


Figure 4.7 Analyzed Data with Altered Start Point

The key steps in editing a Start Point are:

1. Right click on the phase image and go to **Analysis→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 **Analysis→Unwrapping Parameters→Start Point**.
4. Select the Displacement or 3D Graph tab to analyze the data with this 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 4.8** and **Figure 4.9**. Note that in **Figure 4.8** the data is all at a similar height, while **Figure 4.9** 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.

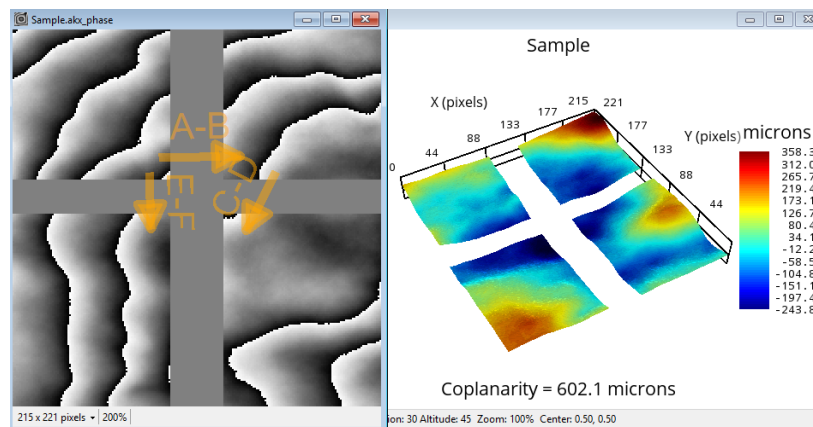


Figure 4.8 Phase-bridged Data at Similar Heights

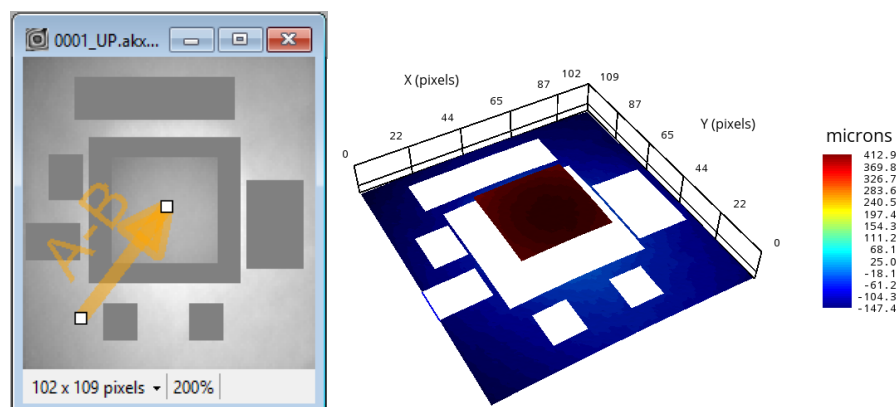


Figure 4.9 Phase-bridged Data with a Step

The key steps in creating a Phase Bridge are:

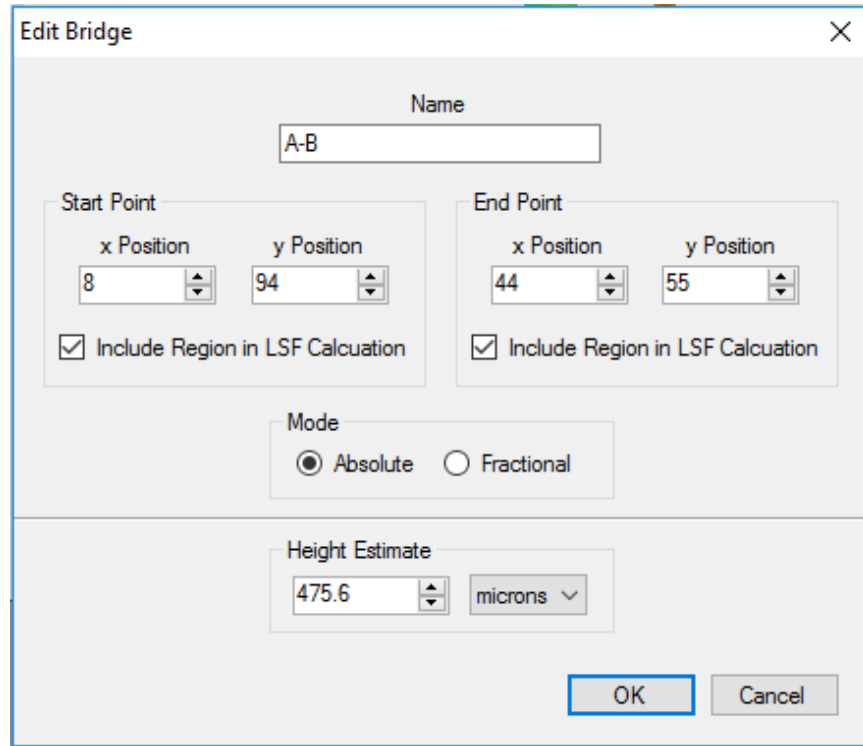
1. Right click on the phase image and go to **Analysis→Unwrapping Parameters→Add Bridge...**, or press **Ctrl+B**.
2. Click on a start and end point in the phase image. Make sure to start in one data "island," and end in another.
3. Surface Analysis will then show a "Rotated" phase image where the data 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 **Analysis→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 4.10 .



The 'Edit Bridge' dialog box is shown with the following fields and options:

- Name:** A-B
- Start Point:**
 - x Position: 8
 - y Position: 94
 - ☒ Include Region in LSF Calculation
- End Point:**
 - x Position: 44
 - y Position: 55
 - ☒ Include Region in LSF Calculation
- Mode:**
 - ☒ Absolute
 - ☐ Fractional
- Height Estimate:**
 - Value: 475.6
 - Unit: microns
- Buttons:** OK, Cancel

Figure 4.10 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.

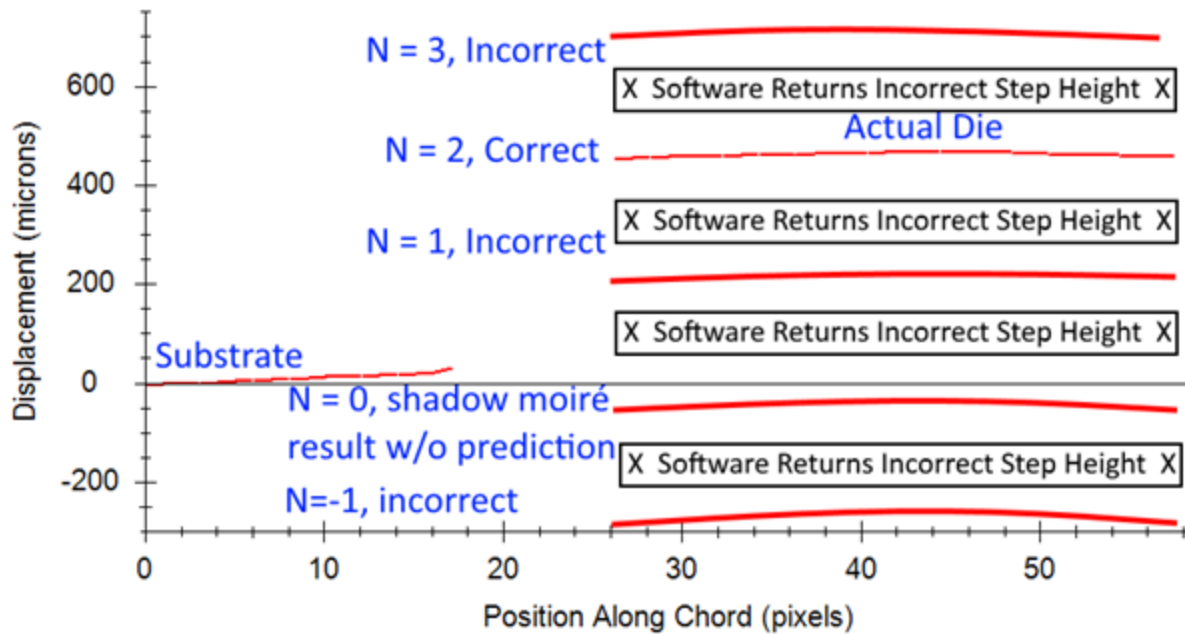


Figure 4.11 Phase Bridge Step Height Example

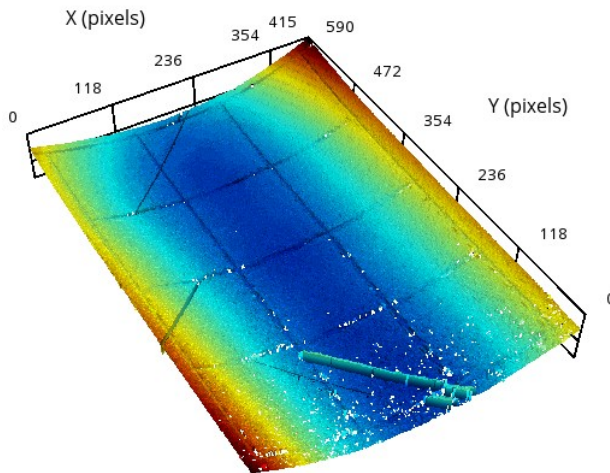


Note: Height estimates must fall within ± 0.25 Fringe Values of the measurement (± 64 microns with the 100 LPI). Height Estimates incorrect by ± 0.25 to 0.75 Fringe Values will generate an error from the software stating an incorrect height estimate. Height approximations incorrect beyond this threshold would lead to incorrect data. This is illustrated in **Figure 4.11** using the same data set from **Figure 4.9**.

4.6.3 Second Diff Quality Mapping

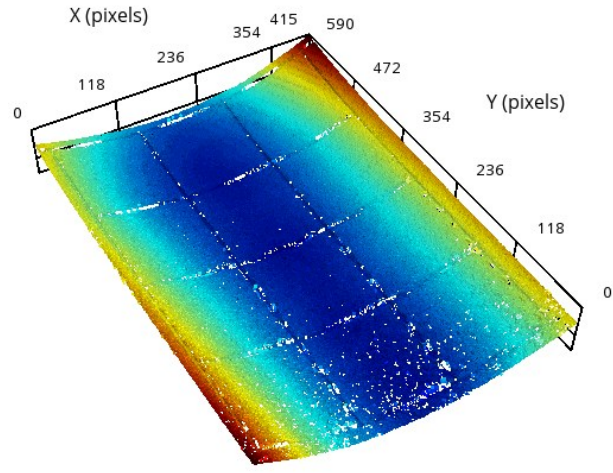
Standard phase unwrapping occurs via a flood-fill algorithm that starts in the center of the image. This process can lead to unwrapping errors when phase quality is poor. The second differences quality mapping routine ranks the quality of the phase, pixel by pixel and follows a path that starts with 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 **Analysis**→**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. The values allowed for the threshold range between 0 – 1000.



Coplanarity = 1224.9 microns

Figure 4.12 Standard Flood Fill Algorithm Unwrapping with Artifacts



Coplanarity = 1159.6 microns

Figure 4.13 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 **Analysis→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.

4.7 Step Height Calculation

Clicking on **Step Height→Add Step** (Figure 4.14) 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 (Figure 4.15 and Figure 4.16). 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.

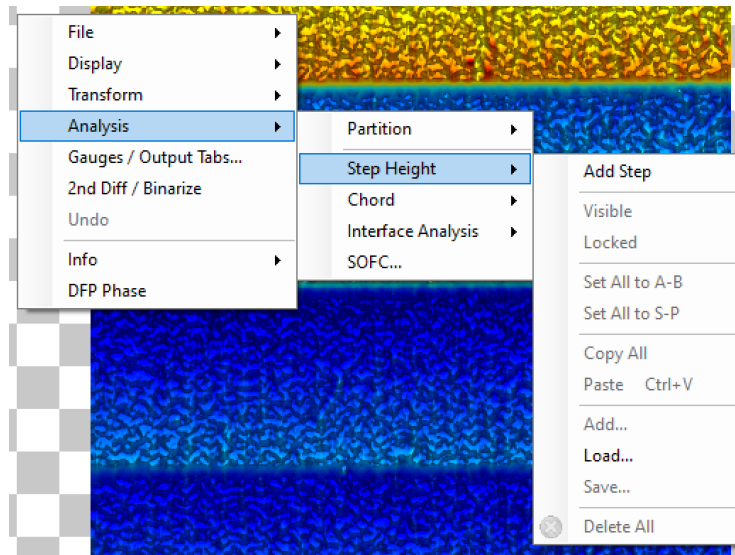


Figure 4.14 Step Height Menu

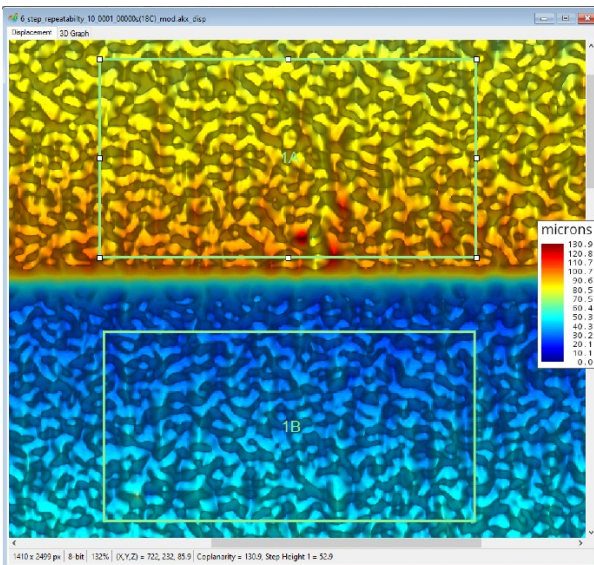


Figure 4.15 Step Height Calculation A>B

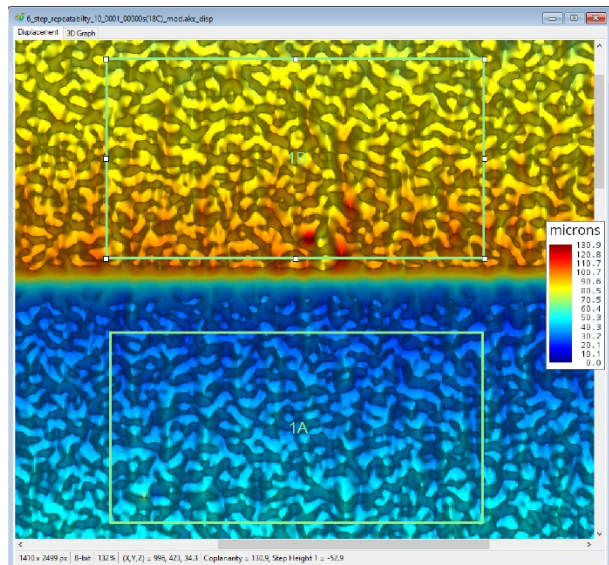


Figure 4.16 Step Height Calculation A<B

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 4.17** and **Figure 4.18** for an example.

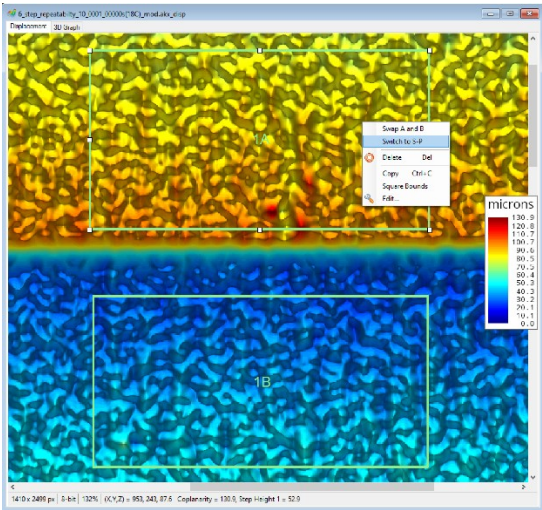


Figure 4.17 A-B Mode

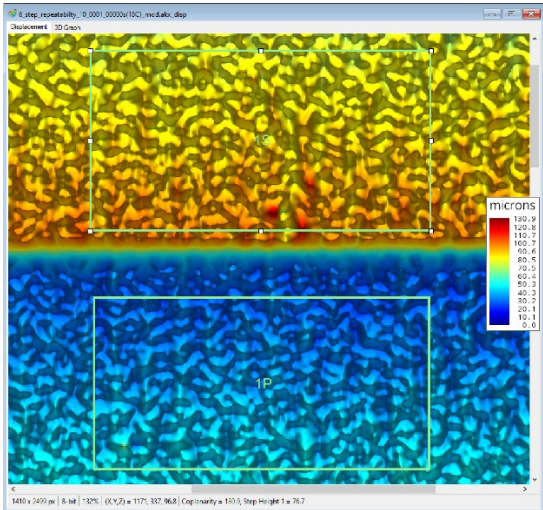


Figure 4.18 S-P Mode

5 Displaying Results

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

- 3D Graph (**Section 5.1**)
- 3D Contour (**Section 5.3**)
- 2D Diagonal (**Section 5.4**)
- 2D Chord (**Section 5.5**)

The data displayed in each graph can be exported in numerical form (**Section 5.6**). Gauges (single values representing the warpage) can be displayed at the bottom of 3D graphs (**Section 5.7**).

5.1 3D Graph

As of Studio 9.1, a 3D Graph tab is shown by default on any open data file. Switch to this tab and the 3D Graph is shown. A context menu similar to that of the displacement image, but with some options removed, is available. See **Section 5.2** for details on the context menu commands. The filename is shown in the 3D graph header and selected gauges are displayed in the footer. Additional information pertaining to the 3D viewpoint is found in the status bar at the bottom. See **Figure 5.1**.

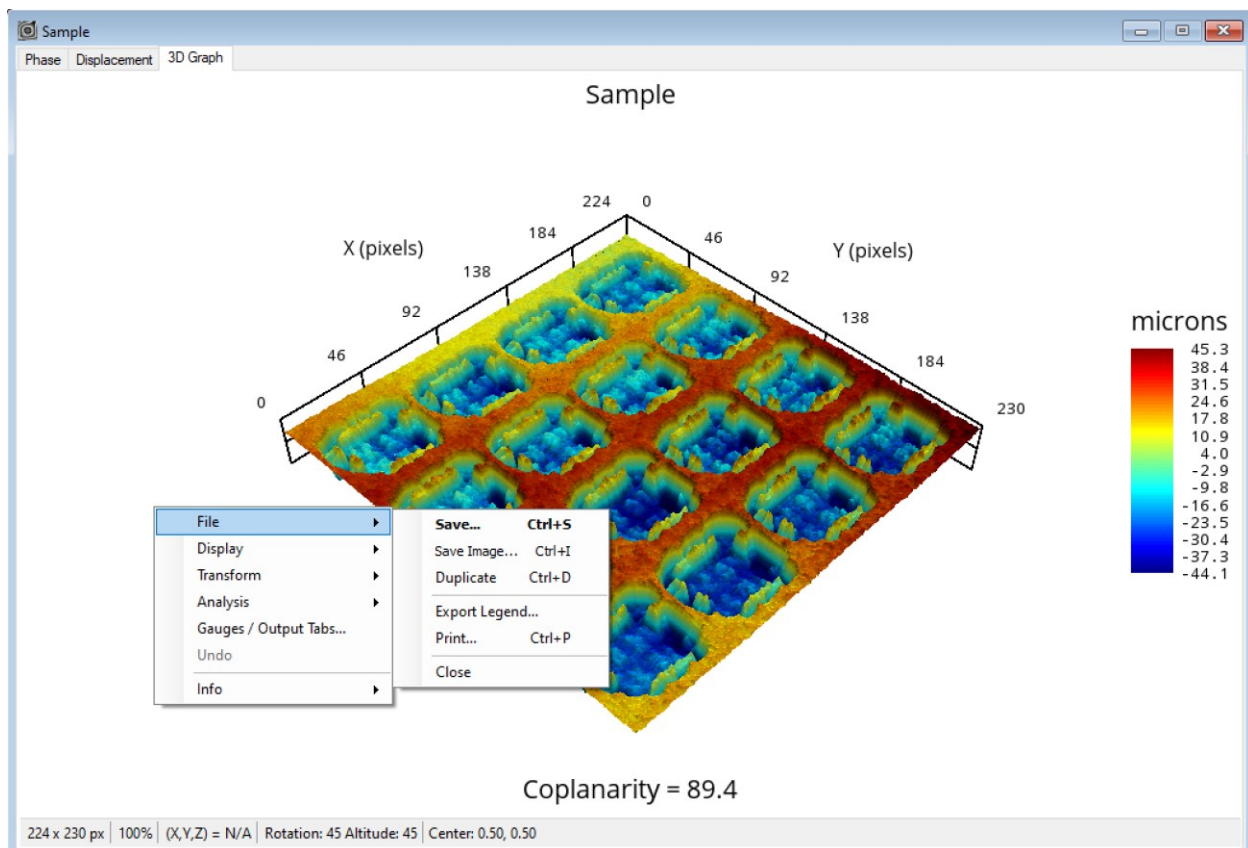


Figure 5.1 3D Graph Plot

5.1.1 Mouse/Keyboard Interactions with the 3D Graph

There are five ways to interact with the 3D Graph:

1. The current mouse cursor position (X,Y,Z) is shown live in the status bar.
2. Left mouse click on the plot and drag it to adjust the angle from which the surface is viewed. Holding the Alt key while pressing an arrow key will also rotate the 3D Graph in the corresponding direction. The current Rotation and Altitude parameters are displayed in the status bar.
3. Scroll the mouse wheel to zoom in or out. Holding the Ctrl key while pressing the + or – keys will also zoom the graph. Ctrl + 0 returns the zoom to the default 100%. As of Studio 9.1, the minimum zoom setting is 100% and mouse wheel scrolling zooms with the center at the mouse pointer location. Subsequent rotate and zoom functions will rotate and zoom about this new point. The current 3D graph magnification level is displayed in the status bar.
4. As of Studio 9.1, holding the middle mouse wheel button down and moving the mouse will pan the 3D Graph. Holding the Ctrl key while pressing an arrow key will also pan the 3D Graph in the corresponding direction. Subsequent rotate and zoom functions operate about this new point.
5. Pressing the Esc key resets the 3D graph back to its original size (zoom ratio of 100%), rotation, altitude, and center point.

5.1.2 Changing Viewpoint

The viewpoint of a 3D graph can be set using five different methods:

- **Window Tabs** section of the **Tools→Options** window (**Section 4.2**)
- **Rotate** and **Pan** operations (**Section 5.1.1**)
- **Duplicate View** in the File command list (**Section 5.2.1**)
- **Copy View** and **Paste View** in the Display command list (**Section 5.2.2**)
- The display **Gauges/Output Tabs...** window (**Section 5.2.2**)

5.2 3D Graph Command List

Right-clicking on the 3D Graph will show a context menu similar to the displacement context menu. The 3D graph context menu is described below.

5.2.1 File

Save...	Saves the data in *.akx_disp format.
Save Image...	Allows display window to be saved in *.png format.
Duplicate	Makes a copy of the current 3D Graph window in memory. As of Studio 9.1, the keyboard shortcut for this command is Ctrl + D.
Export Legend...	Opens a dialog where a legend can be configured and exported as an image in *.png format.

Print...	Allows the current 3D graph view to be sent to a printer.
Close	Closes the window. Prompts to save if any changes are detected.

5.2.2 Display

Copy View	Copies the current 3D Graph rotation, altitude, zoom, center points, and plot cube parameters.
Paste View	Applies a copied view to the current 3D Graph window.
Reset View	Resets all the orientation parameters to those specified in the Gauges/Output Tabs... dialog.
Z-Scale...	Allows the Z-scale units and min/max values to be adjusted.
XY Size	Allows the X and Y data dimensions to be mapped to physical dimensions in either mm or inches. See Section 2.2.5 .

5.2.3 Transform

Smooth	Applies the default or custom smooth function to the displacement data. See AOTA101 for more information.
Plane Rotation	Applies the selected reference plane to rotate the data. See Section 4.3 .
Fit Data...	Opens a dialog (Figure 2.9) where a polynomial fit can be calculated. Alternatively, if physical dimensions are assigned, a spherical fit can be calculated.
Subtract	Calculates and displays the absolute difference between the displacement data of two displacement files. See Section 4.4 .
Invert	Inverts Z data

5.2.4 Analysis

Step Height	This option is greyed out in the 3D Graph tab but can be accessed in the displacement tab.
Interface Analysis	Brings up a list of open *.akx_disp images for showing surface on surface plots from Interface Analysis. See Section 6.3 .
SOFC...	Displays a window containing all Second Order Fit Coefficients used to calculate a 2 nd order polynomial fit for the surface. This list also includes the coefficient of determination, denoted R ² (R squared).

5.2.5 Undo

Allows the user to undo the most recent changes displayed in order of application to the displacement image.

5.2.6 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.

5.2.7 Gauges/Output Tabs...

The Gauges/Output Tabs... window acts to customize the surface gauges calculated, the types of plots available, and change the way the plots are formatted and the data presented on an individual file. This window has been made to appear like the Options window (**Section 4.2**) with only the Gauges and Window Tabs sections available for individual file implementation. The Gauges section allows specific gauges (numerical values quantifying flatness) to be calculated and displayed in the bottom of the 3D Graph. The Window Tabs section allows additional graphs to be displayed as an additional separate tab at the top of the file next to the Phase, Displacement, and 3D Graph tabs. By default, the 3D Graph and Custom Chords tabs will always be present, but checking additional checkboxes in the list will cause their tab to populate.

The 3D Graph tab has a header and footer section that can be changed to display custom information or call out specific metadata associated with the file. The metadata field available can be seen by right-clicking in either the header or footer text entry box selecting **Insert Metadata Tag** and the data tags will be shown in the list. The footer has an additional selection that the header does not, **Insert Gauge Tag**. The specific gauge for this file can be selected to display in footer below the 3D Graph if it is applicable or the requisite data has been entered. The way the data is displayed in the header and footer can also be formatted by selecting **Insert Layout Tag**. A tabbed space between entries for a larger spacing can be selected or starting entries on another line below the other entries can be selected to format data specifically.



Note: If any Step Heights are active from the displacement window, these will automatically display as gauges in the footer of the file's 3D Graph tab alongside any other surface gauge tags entered into the footer field and do not need to be selected as a Gauge Tag to populate.

The checkboxes beneath the header and footer text boxes allow specific additional information and a graphical representation to populate on the 3D Graph such as Legend for the Z-scale and the Z-scale units, The Min & Max Indicators which displays two colored spheres on the 3D Graph surface that identify the lowest and highest Z displacement values with blue identifying the minimum and red identifying the maximum. Pin 1 Indicator requires that the user input this information by Edit Metadata, if this information is present the corner that was identified will display a purple sphere. The Image Annotations selection box allows the user to embed images into the 3D Graphs and alter their position

and size in the 3D Graph. The Rotation, Altitude, and X & Y Center can change the orientation and viewing perspective of the 3D Graph while the Plot Cube while change the scaling of the Z dimension without changing the numerical range of the Z-scale. To return all values to their initial settings the Defaults selection box can be clicked.



Note: The Gauges/Output Tabs... orientation parameters are applied to the current 3D Graph display window (**Figure 5.1**). Copying the view of the current window and pasting to another will only apply to that window as well. These parameters will have to be set in the Options window (see **Section 4.2, Figure 4.1**) to be applied to all newly created 3D Graph display windows.

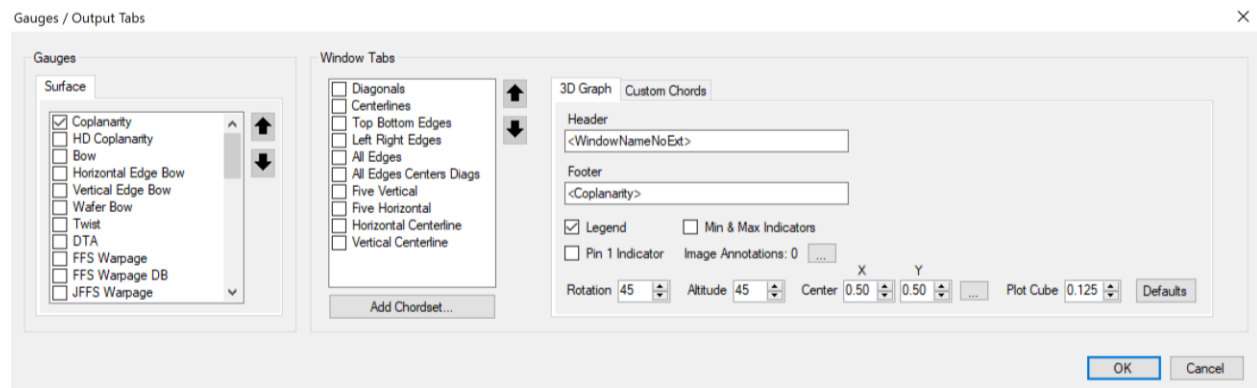


Figure 5.2 Gauges/Output Tabs Window

5.3 3D Contour Plot

The 3D Contour plot is now only accessible through Batch Processing (**Section 7**) to output as an image file (*.png) or to view in the Output tab of the Batch Processing window. The 3D Contour plot can also be selected as an Output Option in Create Report (**Section 8.3.2**). As of Studio 9.1, the Color Contour output now has 16 contour lines on the surface as in **Figure 5.3**. To generate a top-down color output without these contour lines the 2D Disp Image output option can be selected in both Batch Processing and Create Report.

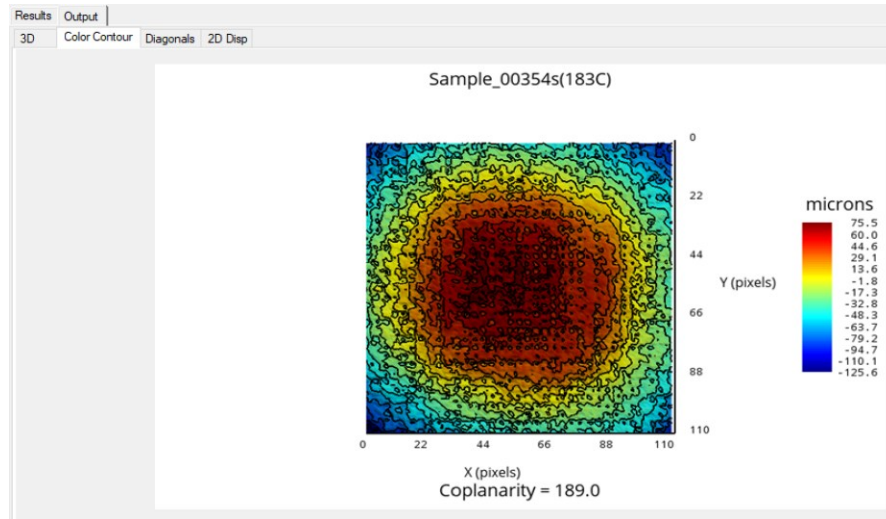


Figure 5.3 Batch Processing Color Contour Plot

5.4 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 **Window Tabs** list in **Tools→Options**, and checking them there causes these chord plots to come up automatically as new window tabs when opening a new phase or displacement image.

The plot window for any of these common chord plots, along with some other default chords, can also be opened by right-clicking in the Phase, Displacement, or the 3D Graph tab window and selecting **Gauges/Output Tabs....** Selecting any of the chords in this manner will apply to just the singular file that it is accessed from. A full list of available default chords is below.

- Diagonals



Note: The diagonal plot (**Figure 5.4**) represents two cross-sections of the surface along diagonal lines connecting the corners. The Downward Diagonal runs from top left to bottom right and the Upward Diagonal runs from bottom left to top right.

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



Note: All horizontal chords are plotted from left to right and all vertical chords are plotted from top to bottom.

The chord plot can be zoomed in using the mousewheel or by clicking and dragging a box around the area of interest.

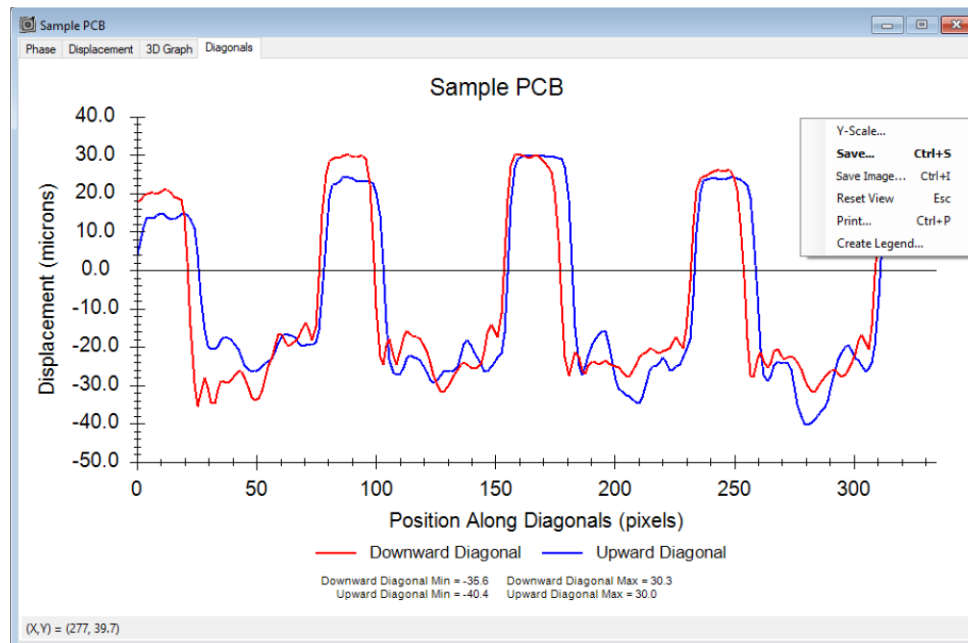


Figure 5.4 Diagonal Plot

5.4.1 Chord Plot Command List

Right-click inside the chord plot window to show the command list (**Figure 5.4**).



Note: Normalization of the chord is no longer accessed via the chord context menu. This option is now available on the applicable chord tab in **Gauges/Output Tabs...** or in **Tools→Options**.

The following commands are available:

Y-Scale...	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 5.6)
Save Image...	Allows display window to be saved in graphical format (*.dia.png).
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.

5.5 Custom Chord Plots

In addition to the default chords described in **Section 5.4**, 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.

5.5.1 Creating a Chord

Right-click inside the displacement tab and select **Analysis→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.

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.

5.5.2 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 start and endpoint positions to be set to specific pixel values using text boxes. Also allows renaming of the chord.
Reverse Direction	Reverses the direction by switching the start and endpoint positions 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 **Add Chord...** is selected, the Custom Chords tab appears to the right of the 3D Graph tab in the file it is being added to. All display commands available for Diagonal plots are applicable here, including exporting the chord displacement data in numerical form.

5.5.3 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 displacement image. Additional chords added using **Analysis→Chord→Add Chord** become part of this set.

A set can be saved by right-clicking on the displacement image and choosing **Analysis→Chord→Save...** and a saved set can be loaded by choosing **Analysis→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. They can additionally be applied to all newly opened phase or displacement files in **Tools→Options** by selecting **Add Chordset...** and selecting the desired chord set file. This can be done on individual files as well through the **Gauges/Output Tabs...** menu.



Note: If a loaded chord set was generated from a displacement image of a different size than the current one, a window will warn of the size mismatch and ask if the chords should be scaled to the current layout's pixel dimensions or preserve the original chord sized for the original layout. If the original displacement window was larger and preserve original layout is selected only the chords with both ends falling within the current image in that set will be loaded and a window will appear detailing how many chords in the chord set were discarded and how many were trimmed to fit.

A chord or set of chords can be made visible or invisible by going to **Analysis→Chord→Visible**. A checkbox will appear next to **Visible** if there are chords on the displacement image. **Analysis→Chord→Locked** prevents moving or interacting with chords. Similarly, when this is selected a checkbox will appear next to **Locked** to indicate that the chords cannot be moved or interacted with.

5.5.4 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

Top Bottom Edges	_hze	.png
Vertical Centerline	_vte	.png
Left Right Edges	_vte	.png
Centerlines	_cen	.png
Five Vertical	_5vl	.png
Five Horizontal	_5hl	.png
All Edges	_edg	.png
All Edges Centers Diags	_ecd	.png
Arbitrary	_crd	.png

5.6 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 Graphs have slightly different context menus and save options, as described in **Section 5.2** .

- Akx_disp** Exports data in the Akrometrix *.akx_disp format (not available for chords)
- Dat files** Exports data in tab-delimited text format (*.dat)
- Text files** Exports data in space-delimited text format (*.txt)

Dat and text files containing chord data will use the same prefixes as chord image files, as described in **Section 5.5.4**.

5.7 Gauge Output

Gauges can be selected in the **Gauges** list in the Options window for all newly opened phase and displacement files or in **Gauges/Output Tabs...** for an individual file. They are displayed at the bottom of Displacement windows and in the footer of 3D Graphs. 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 overlays 3D plots to visualize and quantify gaps across the interface. It can also generate Gap pass-fail warning maps to highlight interconnect areas that may fail. IA can be used on a single pair of acquisitions (see **Section 6.3**), or in batch (**Section 9**) for many sets of surfaces.

6.1 Orientation and Registration using IA Metadata

To properly orient the two surfaces being analyzed, the following metadata fields are introduced. These can be set during acquisition in Surface Measurement or during analysis (see)

1. Pin 1 Location: Identifies which of the four corners of the measured surface contains Pin 1. (Lower Left, Upper Left, Upper Right, or Lower Right)
2. Measured Side: Identifies whether the measured surface is the attach or non-attach side of the BGA of the PCB of the interface of interest. (Inner or Outer)
3. Interface Location: Identifies whether the measured surface is physically positioned above or below the other measured surface in the interface of interest. (Top or Bottom)

Correctly defining the interface stack of interest is essential for setting up Interface Analysis. In a typical electronic package assembly, there are only single interface stacks of interest. A common example is a BGA mounted on a PCB, as in **Figure 6.1**.

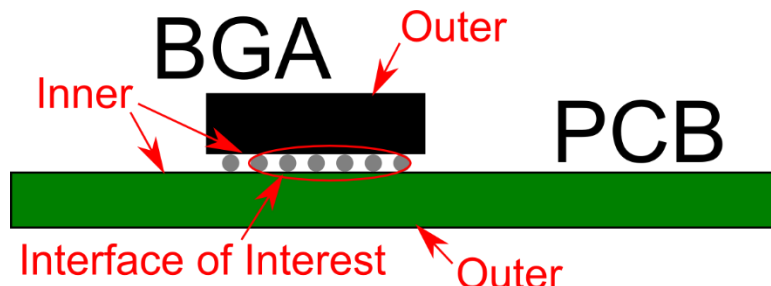


Figure 6.1 BGA on PCB Interface Stack

When multiple interface stacks are present, however, **Measured Side** and **Interface Location** must be defined relative to the specific interface being analyzed. As a result, these designations may change from one analysis to another. In the examples shown in **Figure 6.2** and **Figure 6.3**, the sandwiched substrate may be designated as either top or bottom, and as either inner or outer, depending on which interface is being studied.

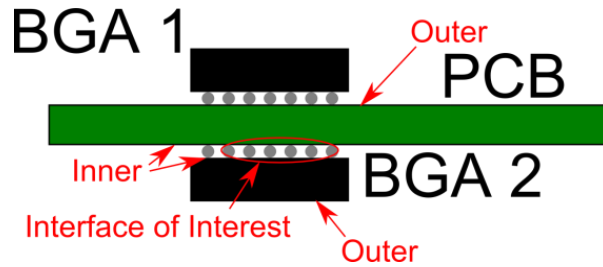


Figure 6.2 BGAs on both sides of a PCB

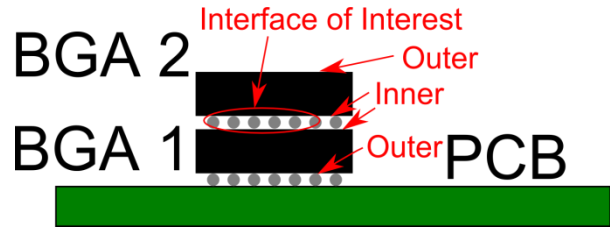


Figure 6.3 PoP on a PCB

For example, if the top interface is analyzed in **Figure 6.2**, the top surface of the PCB is considered an **inner** surface. If the bottom interface is analyzed, that same surface is considered **outer**. Similarly, in **Figure 6.3**, the surface designations for the sandwiched BGA depend on the interface of interest. When analyzing the interface between BGA 1 and BGA 2, the top side of BGA 1 and the bottom side of BGA 2 are both considered **inner** surfaces.

Once the interface of interest has been defined and the inner/outer and top/bottom assignments have been made, the software can rotate and/or flip the data so that the pin 1 locations on the two surfaces align.

If the **inner** surface of a **top** part is being analyzed, the software flips the data and then rotates it so that Pin 1 aligns correctly. If the **outer** surface of that same part is measured, the data is not flipped. Whether a surface is flipped depends on the combination shown in **Table 6.1**. After any required flipping is applied, the software will rotate each surface such that Pin 1 is in the same corner for both the 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

6.2 Offset Methods

Another important consideration when analyzing the interface between two surfaces is the method used to offset the surfaces relative to 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 translated towards one another while maintaining parallel LSF planes, until the first point of contact occurs. An example using the Maximum surfaces from **Figure 9.9** and **Figure 9.10** is shown below.

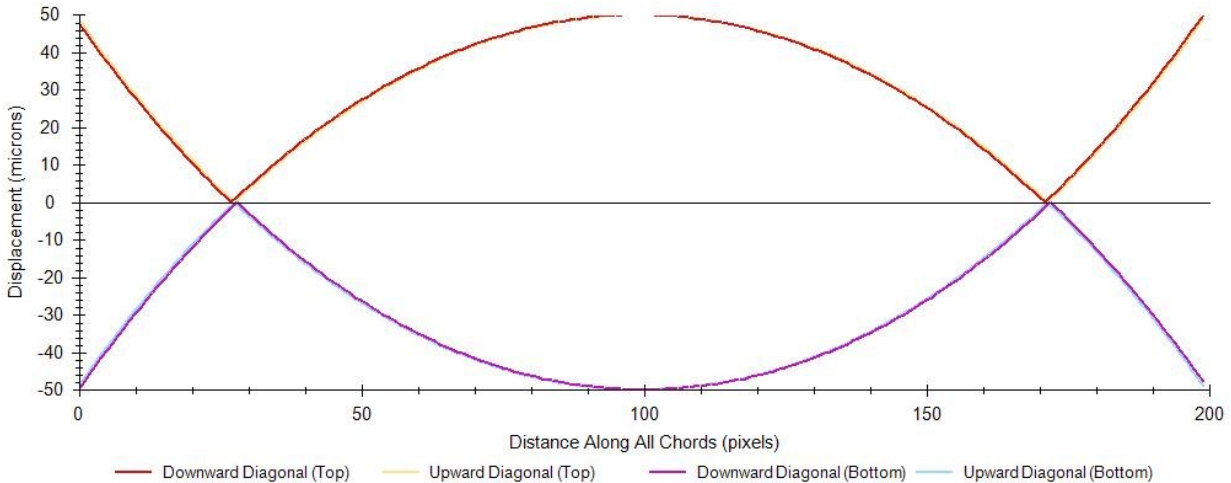


Figure 6.4 Example Diagonals of Closest Point Touching Offset Method

6.2.2 Closest Point Offset

This offset method operates the same way as *Closest Point Touching*, but includes an additional user-defined offset value. This value can be used to account for solder ball height or other attachment interface materials.

6.2.3 Center Gap Constrained

In this method, a 10 x 10 pixel area at the center of the top surface is averaged. This average value is then offset by a user-defined amount to a similarly calculated average value on the bottom surface. In the example below, the offset was set to 0.

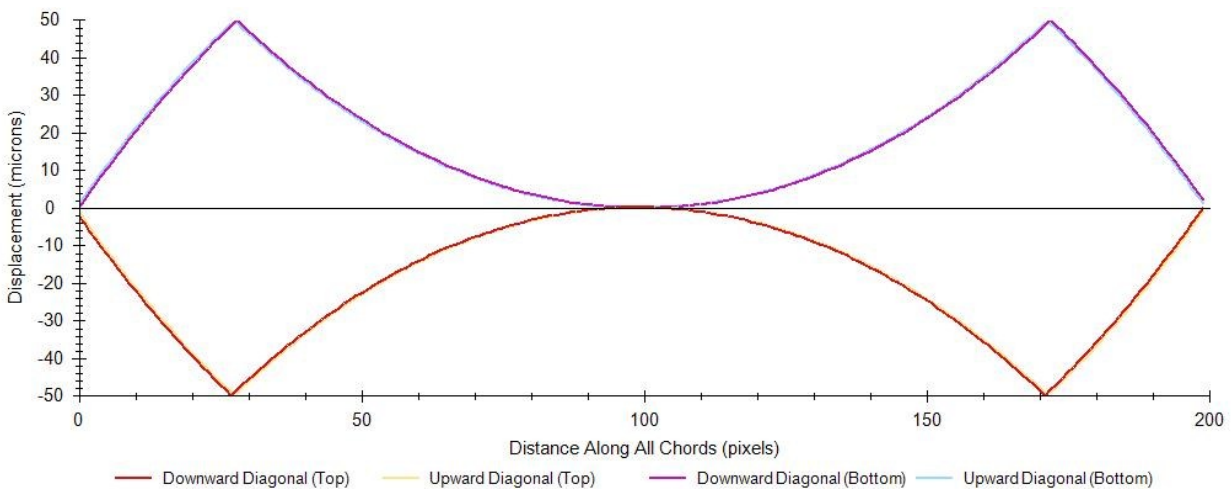


Figure 6.5 Example Diagonals of Center Gap Constrained Offset Method

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 was set to 0.

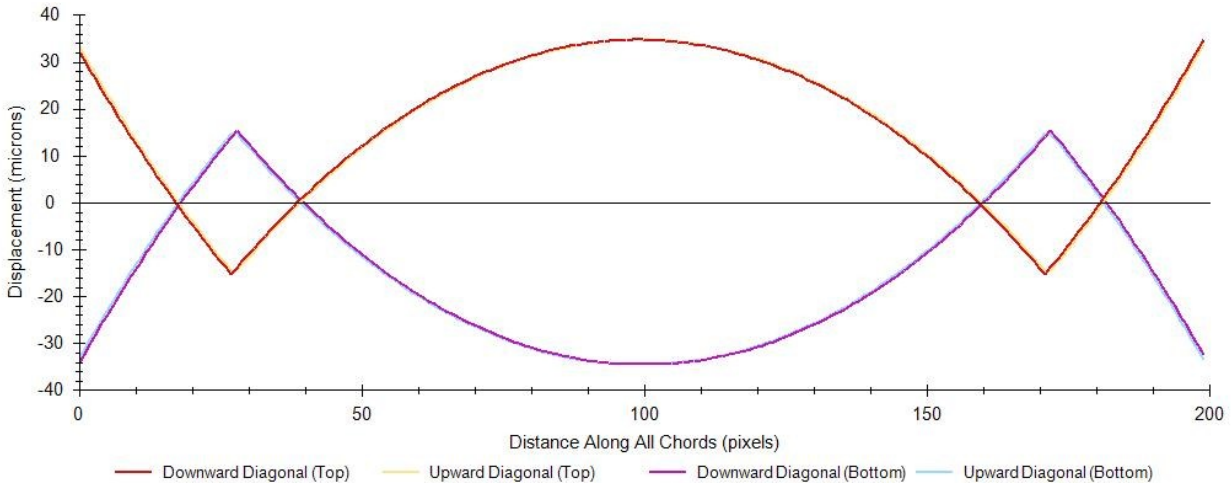


Figure 6.6 Example Diagonals of Edge Gap Constrained Offset Method

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.

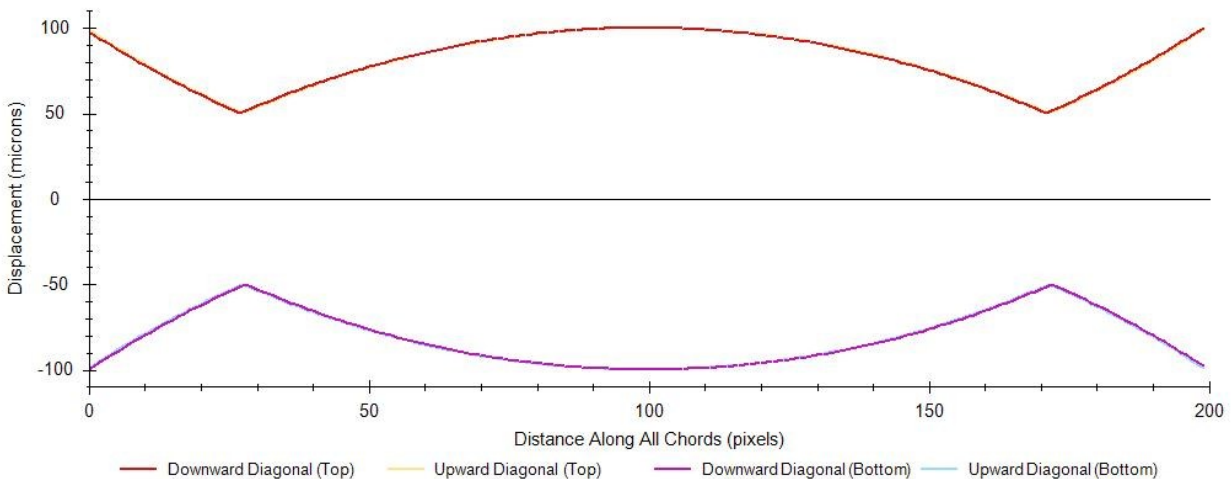


Figure 6.7 Example Diagonals of Datum Plane Fixed Offset Method



Note: Datum Plane Fixed is most useful in Batch 1A 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

Interface Analysis is launched from the context menu of either a Displacement or 3D Graph tab. Under the **Analysis** submenu, another open displacement file can be selected as the comparison surface. If the desired displacement is not already open, it can be loaded by selecting **File...** at the bottom of the list and browsing to the file on disk. (**Figure 6.8**)

Image size mismatch is noted next to each entry with a green check mark, yellow triangle, or red X, indicating how reasonable the size agreement is.

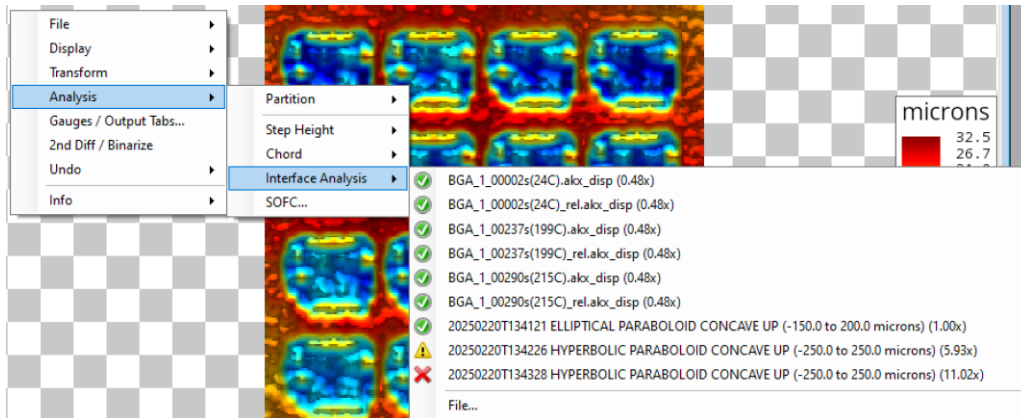


Figure 6.8 Selecting a file for Interface Analysis - One-Off

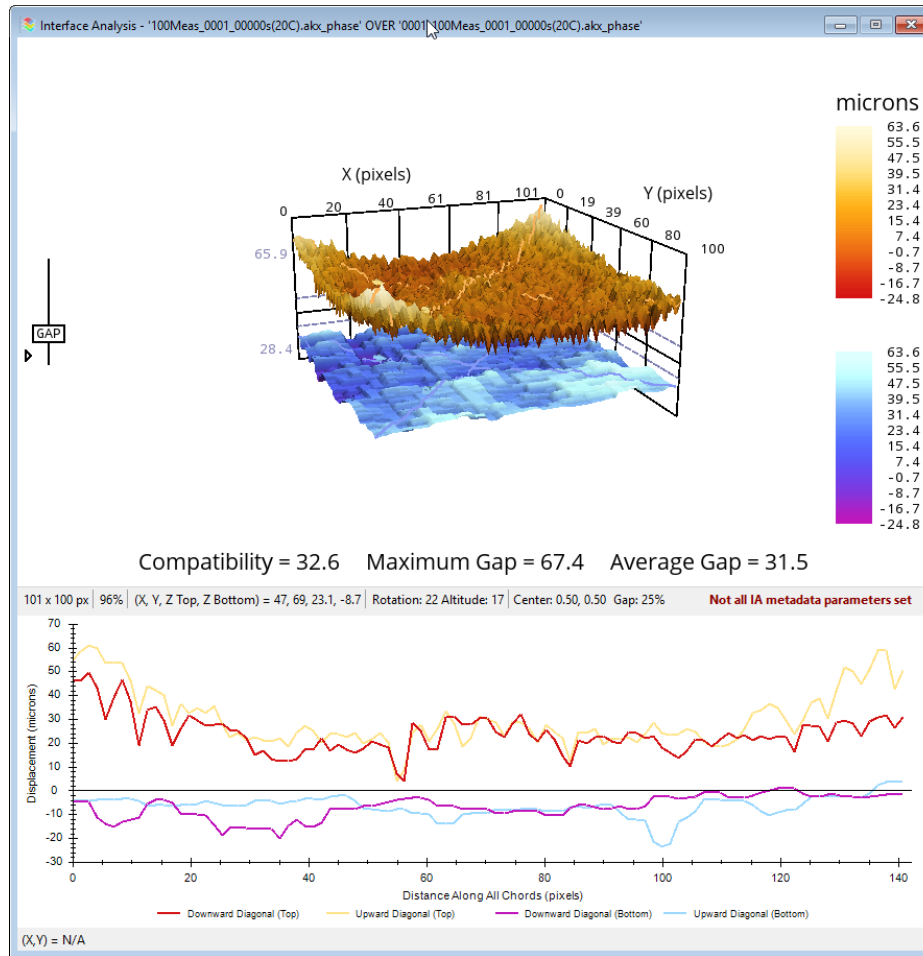


Figure 6.9 IA One-Off Result Window

Once a comparison file is selected, a result window opens as shown 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 control affects visualization only and does not change the gauge calculations.

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 is applied, and the file from which Interface Analysis was initiated is treated as the bottom surface. A note will appear indicating that IA metadata parameters have not been set (**Figure 6.10**).

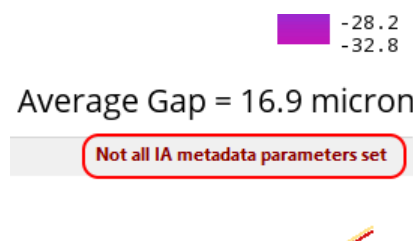


Figure 6.10 Not all IA metadata parameters set

The IA 3D plot can be saved and its display can be adjusted from the right-click context menu (**Figure 6.11**). The **File** menu allows the 3D plot to be saved as a *.png image. As of Studio 9.1, Gap plots can also be saved as displacement files (*.akx_disp) via **File→Save....** Under **Display**, views can be copied/pasted between open 3D plots, and the current view can be reset to default parameters. The **Settings Panel** controls how the top and bottom surfaces are displayed. Each surface can be displayed as **Solid**, **Transparent**, or **None** (not displayed at all). Enabling **Wireframe** overlays a checkerboard pattern of horizontal and vertical lines on the surface to aid in contour visualization. The Wireframe color can be set to either match the surface color or black for greater contrast.



Note: When either surface is set to None, Wireframe is enabled automatically.

The currently selected chord locations can be shown or hidden by the **Chords** checkbox and chord directions can be shown or hidden using the **Arrows** checkbox. The **Planes** checkbox displays transparent green planes connecting the selected chords between the top and bottom surfaces.

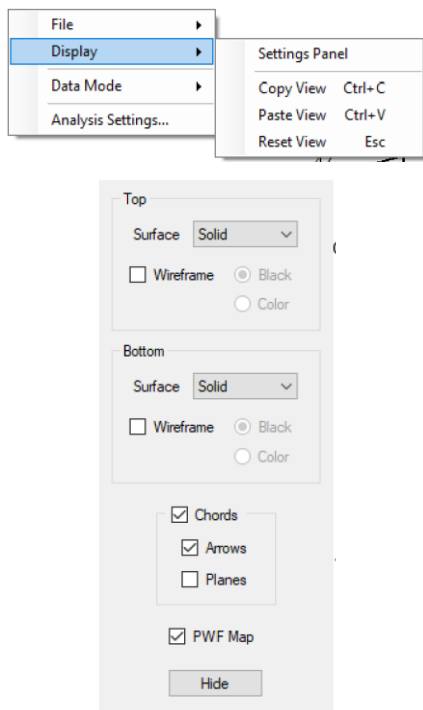


Figure 6.11 IA 3D Plot Context Menu and Settings Panel

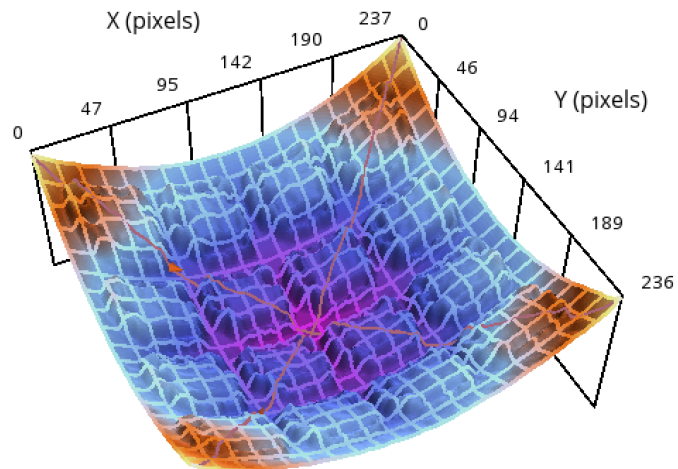


Figure 6.12 IA Gap mode plot

A PWF (pass/warning/fail) map can be displayed as a third surface between the top and bottom surfaces (**Figure 6.13**) if the Gap Limits have been set in **Analysis Settings...** (**Figure 6.15**). The PWF map highlights areas where the calculated gap falls within or exceeds the defined warning and limit thresholds.

The **Data Mode** can be changed between **Top/Bottom** and **Gap**. In **Gap** mode, the dual-surface display is replaced with a single surface representing the gap between the two surfaces. Larger z-values correspond to where the gap distance is greater (**Figure 6.12**). The PWF map can also be displayed on the **Gap** mode plot (**Figure 6.14**).

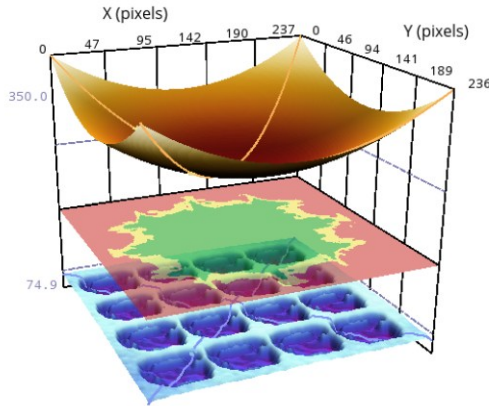


Figure 6.13 PWF map between Top and Bottom surfaces

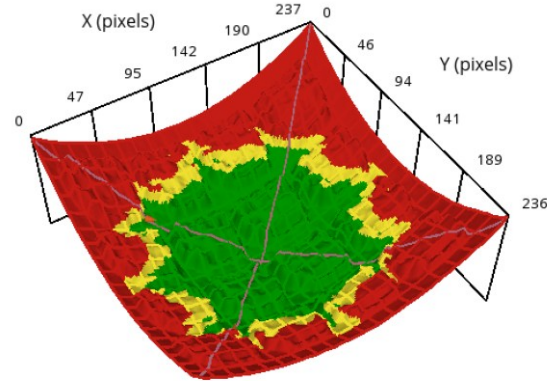


Figure 6.14 PWF map overlay on Gap plot

Analysis Settings is available from the context menu (**Figure 6.15**). This dialog is used to enter physical dimensions, change Z-units between microns and mils, define PWF limits, and select gauges. Settings files (*.akx_IASettings) can be saved and loaded via a File menu.



Note: PWF limit assignments are always in microns, regardless of Z Unit selection. By Default, the Gap/Warning parameters are not checked or defined and have to be set by the user to be included in the analysis.

If the pixel dimensions of the two surfaces do not match, the smaller surface is grown by default, but the opposite can be selected using the **Surface Resizing Method**. The **Surface Offset Method** described in (**Section 6.2**) can be selected, along with the corner used for Pin 1 alignment through **Pin 1 Alignment Location**.

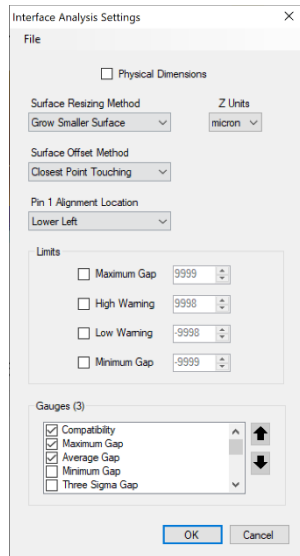


Figure 6.15 Interface Analysis Settings

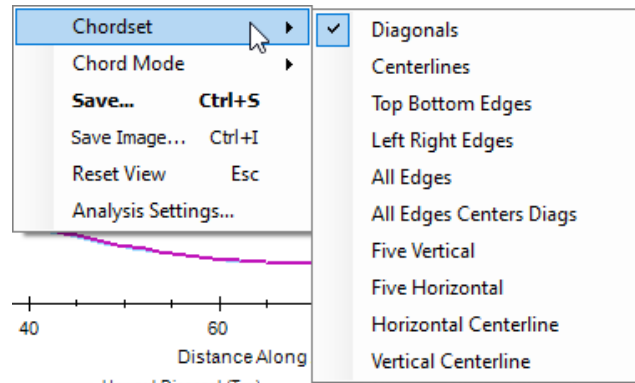


Figure 6.16 Interface Analysis Chord Context Menu

The chord section context menu (**Figure 6.16**), accessed by right-clicking in the chord plot area below the 3D plot section, allows selection of different chord groups and modes. The currently displayed chord set can be saved as either a picture or data file.

6.4 Gauges

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

7 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.

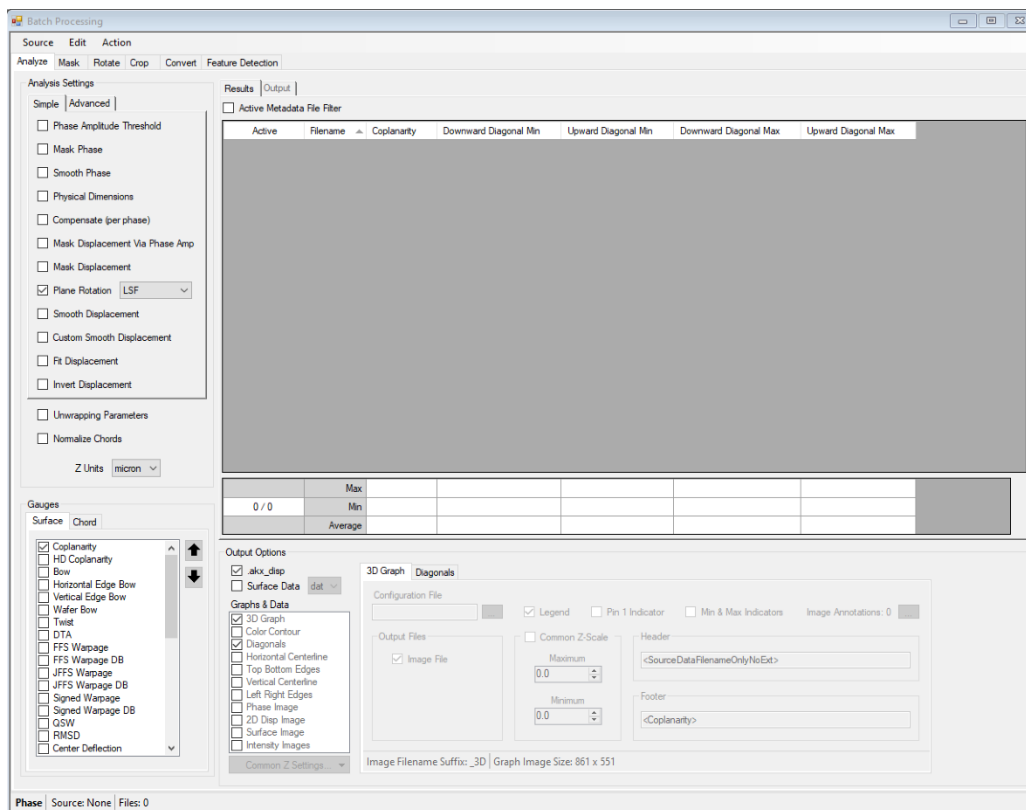


Figure 7.1 Batch Processing Screen

7.1 Batch Analysis

The batch analysis function opens phase 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. Multiple folders can be analyzed via a pop-up folder selector. See Section 7.1.1 .
Edit → File Type	Switches between analyzing phase (*.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 → 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 can be changed in Tools→Options (Section 4.2) to either .txt or .xml.
Action → Analyze	Analyzes the phase or displacement files loaded into the file list with the Analysis Settings that have been entered.
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 7.1.5 .

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 that the files be reanalyzed.

Action → Create Report...

Opens the report creation window with analysis data from the Current Batch pre-loaded in memory.

7.1.1 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.

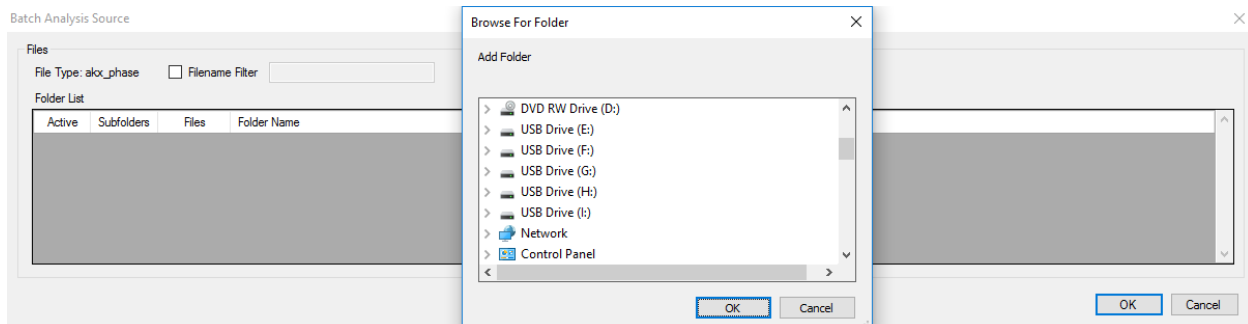


Figure 7.2 Batch Analysis Source Selection Browse for Folder

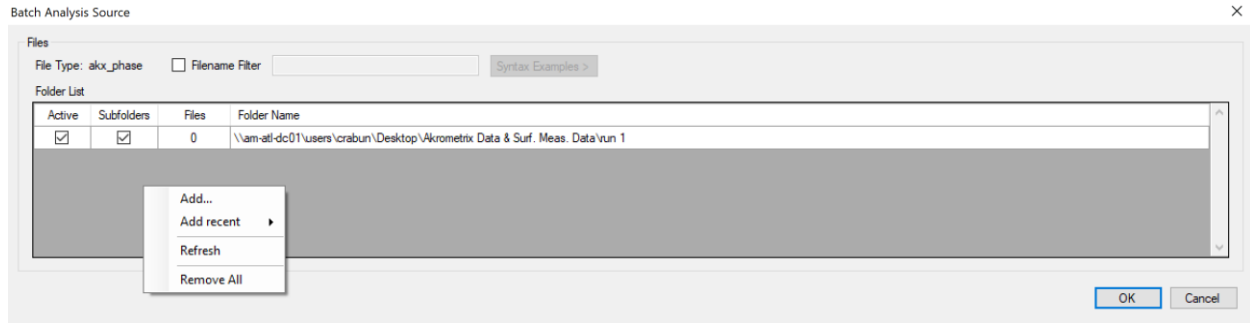


Figure 7.3 Batch Analysis Source Selection Add Folders

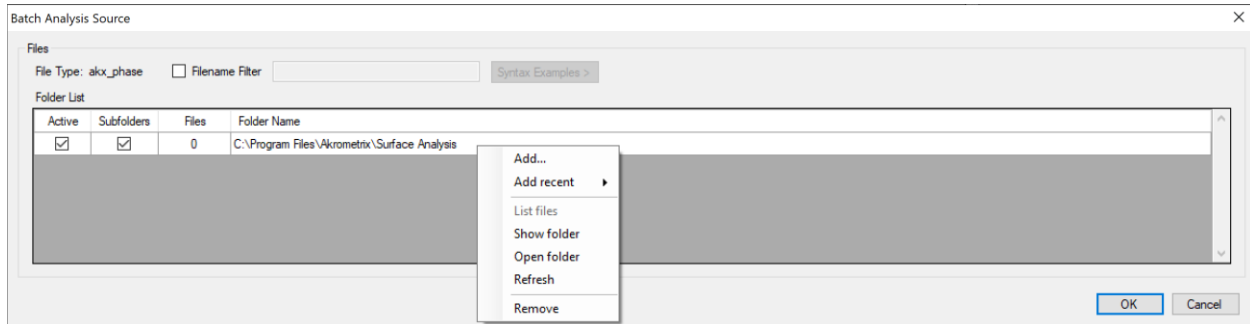


Figure 7.4 Batch Analysis Source Selection Add Right Click on Folder Menu

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 surface 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.

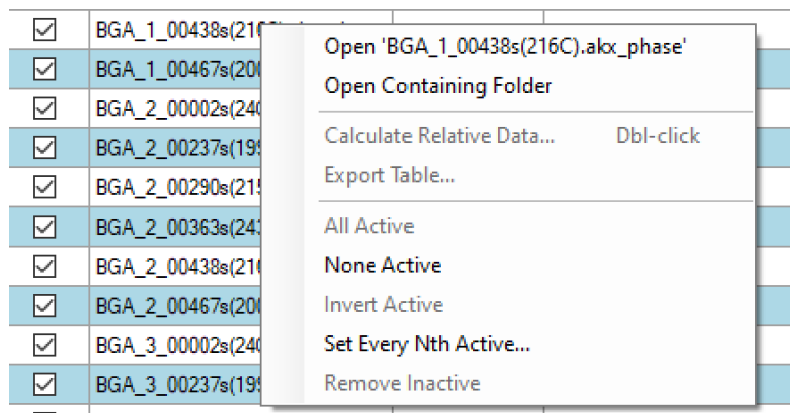


Figure 7.5 Analysis Results Table with Context Menu

3. Select analysis options (**Section 7.1.3**) and any additional columns of metadata required (right click on column headers in Results tab - **Figure 7.6** and **Figure 7.7**).

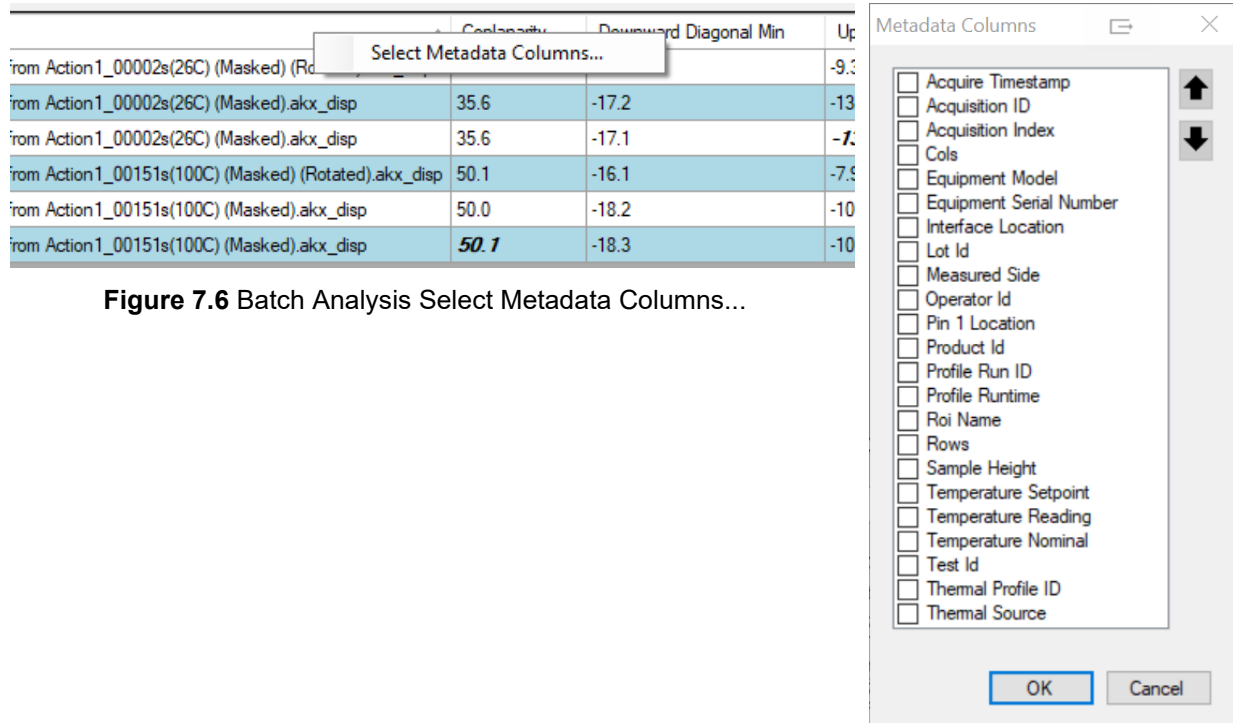


Figure 7.6 Batch Analysis Select Metadata Columns...

Figure 7.7 Batch Analysis Metadata Column Selector

- Analyze the measurement data (**Action→Analyze** menu item). Gauge results are written to the table. The Max, Min, and Average values of each gauge are shown below, which provide the default scale for generating plots. A Batch Results.txt file is written to each top-level directory of the input folders. Displacement files (*.akx_disp or *_mod.akx_disp) are written to the disk as well as surface data, if selected.

Active	Filename	Coplanarity	Downward Diagonal Min	Upward Diagonal Min
☒	BGA_3_00237s(199C).akx_phase	50.4	-25.5	-13.1
☒	BGA_3_00290s(215C).akx_phase	55.3	-29.9	-10.1
☒	BGA_3_00363s(243C).akx_phase	62.3	-34.5	-10.1
☒	BGA_3_00438s(216C).akx_phase	52.8	-31.1	-10.1
☒	BGA_3_00467s(200C).akx_phase	43.2	-23.8	-10.1
☒	BGA_4_00002s(24C).akx_phase	81.6	-31.7	-10.1
☒	BGA_4_00237s(199C).akx_phase	50.5	-27.8	-10.1
☒	BGA_4_00290s(215C).akx_phase	60.2	-29.0	-10.1
☒	BGA_4_00363s(243C).akx_phase	62.3	-34.5	-10.1
☒	BGA_4_00438s(216C).akx_phase	52.8	-31.1	-10.1
☒	BGA_4_00467s(200C).akx_phase	43.2	-23.8	-10.1
☒	Sample_00001s(26C).akx_phase	50.4	-25.5	-13.1
☒	Sample_00196s(150C).akx_phase	50.4	-25.5	-13.1
☒	Sample_00261s(183C).akx_phase	50.4	-25.5	-13.1
☒	Sample_00314s(220C).akx_phase	50.4	-25.5	-13.1
☒	Sample_00354s(183C).akx_phase	50.4	-25.5	-13.1
☒	Sample_00999s(26C).akx_phase	50.4	-25.5	-13.1
Max				
		201.1	-18.3	-10.1
Min				
		43.2	-108.4	-10.1
Average				
		83.3	-42.3	-10.1

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.

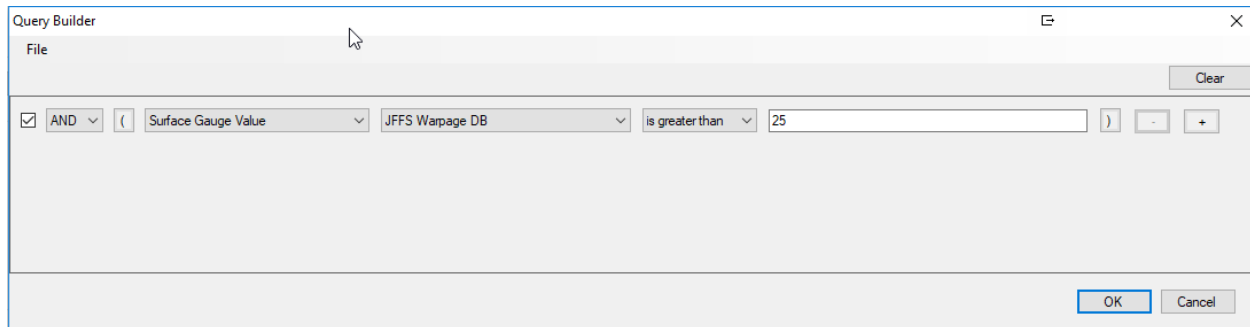


Figure 7.9 Metadata File Filter Query Builder



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 Error! Reference source not found.**) to create a formatted pdf report, or create and save images of the results using the **Action→Generate Output** functionality (see **Section 7.1.5**). Settings for the latter are found under Output Options (see **Section 7.1.4**).

7.1.2 Using Batch Analysis to Create Relative Plots

In order to set one of the images in the selected folder as a reference image (see **Section 4.4**), after first performing a regular Batch Analysis, double-click or right click on the file in the in the summary table and select Calculate Relative Data... (**Figure 7.10**). Confirm in the resulting dialog (**Figure 7.11**) that all analysis should use its height data as reference. All data will then be reanalyzed as relative to this reference surface. In the source folder, new output files showing the resulting subtracted surfaces will be created by appending the original filename with “_rel”.

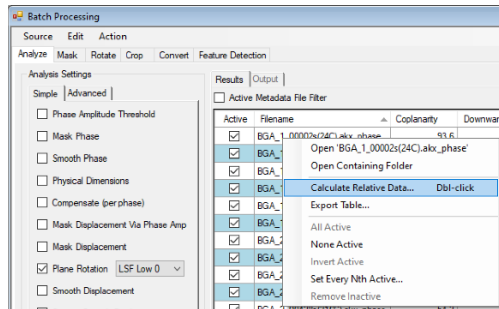


Figure 7.10 Calculate Relative Data...

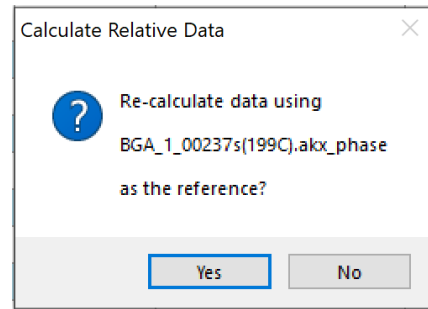


Figure 7.11 Calculate Relative Data

Subsequent outputs or reports can be generated per normal procedures. These will all populate with recalculated numbers showing the selected reference file gauges as 0 (Figure 7.12 and Figure 7.13).

Results

Output

☐ Active Metadata File Filter

Active	Filename	Coplanarity	Downward Diagonal Min	Upward Diagonal Min	Downward Diagonal Max	Upward Diagonal Max
☒	BGA_1_00002s(24C).akx_phase	116.2	-45.1	-47.6	63.6	58.2
☒	BGA_1_00237s(199C).akx_phase	0.0	0.0	0.0	0.0	0.0
☒	BGA_1_00290s(215C).akx_phase	32.2	-4.9	1.4	19.5	15.0
☒	BGA_1_00363s(243C).akx_phase	42.1	-4.9	-2.8	20.6	21.2
☒	BGA_1_00438s(216C).akx_phase	25.3	-5.0	-3.5	9.4	10.6
☒	BGA_1_00467s(200C).akx_phase	23.5	-7.3	-7.2	8.6	6.7
☒	BGA_2_00002s(24C).akx_phase	143.8	-53.5	-52.0	89.0	46.2
☒	BGA_2_00237s(199C).akx_phase	53.2	-15.5	-29.7	16.4	3.3

Figure 7.12 Batch Relative Data Results Table

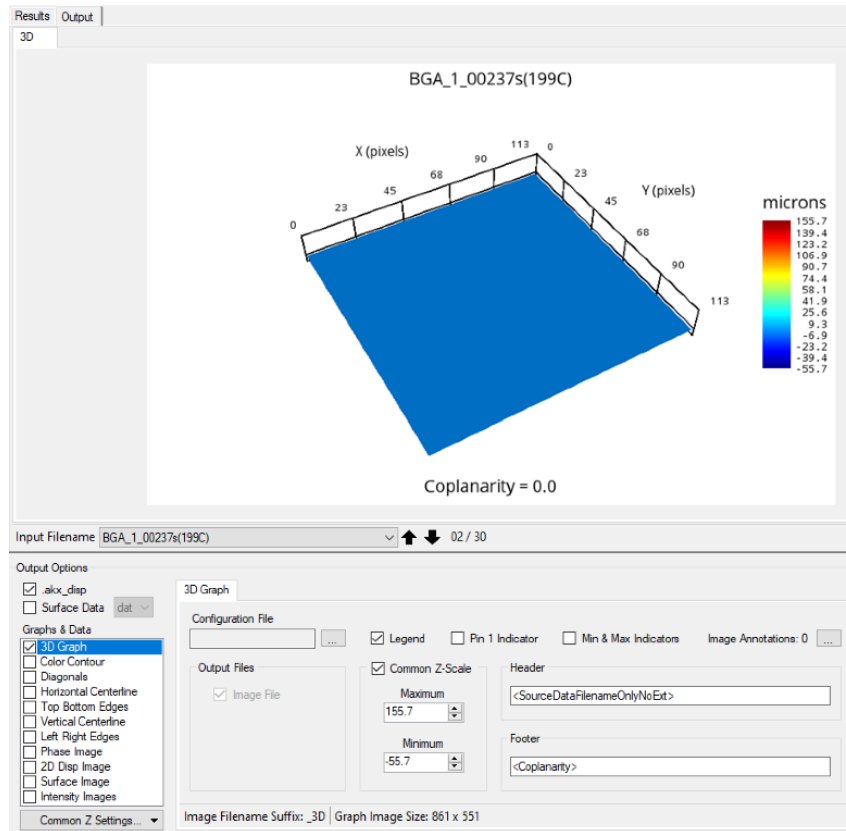


Figure 7.13 Batch Relative Data Output 3D Graph

7.1.3 Analysis Settings



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

Analysis settings are grouped into a Simple and Advanced mode. The Simple mode applies the selected filters in top to bottom order. The Advanced mode allows additional flexibility in applying filters in different orders and multiple times.



Note: Many of the gauges listed below are abbreviated. Hovering the mouse cursor over a given gauge 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 3.2**). A dialog appears with these options when checked.

Mask Phase

Applies a previously created mask to phase images before analysis (see **Section 3.1**). A Load Mask window appears when the box is checked.

Smooth Phase	Applies a smoothing function once to phase images before analysis (see Section 3.4)
Physical Dimensions	Assigns a specific physical size to each data file (see Section 2.2.5).
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 3.2). A dialog appears with these options when checked.
Mask Displacement	Applies a previously created mask to displacement files before analysis (see Section 3.1). 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 default 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 2.9 . Alternatively, if physical dimensions are assigned to the phase image, a spherical fit can be calculated.
Fill Displacement Holes	Fills holes in the displacement data being analyzed. See Section 3.6 .
Invert Displacement	Inverts Z data
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 5.4.1).
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 and the box checked to select by double clicking on that gauge. 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 chord sets (*.akx_chordset).

In the Advanced mode, filters can be added 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.

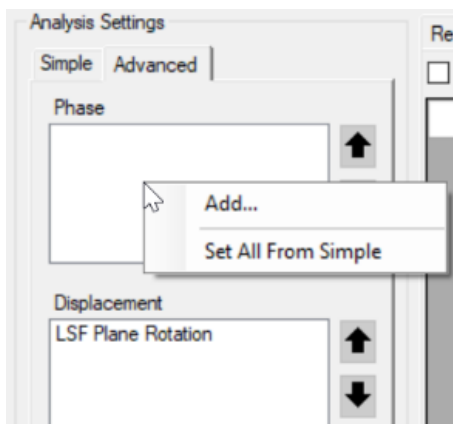


Figure 7.14. Analysis Settings Advanced Mode

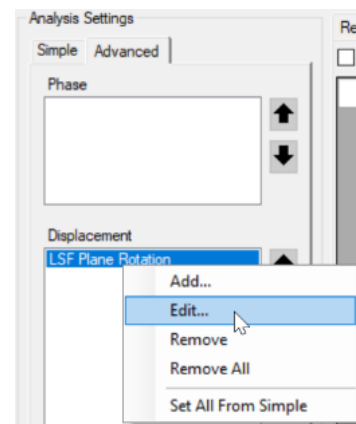


Figure 7.15. Analysis Settings Advanced Mode Edit Filter

7.1.4 Output Options

These options affect the results of the **Action→Generate Output** command (See **Section 7.1.5**).

.akx_disp Saves *.akx_disp files to disk during analysis when analyzing phase files. When displacement files are the input, *_mod.akx_disp files are saved to denote the modified displacement files. Unlike other outputs, displacement files are saved during the Analyze step.

Surface Data Saves the raw data of the files and can be exported as *.dat, *.txt, or *.csv, for importing into other numerical analysis programs. Unlike other outputs, Surface Data files are saved during the Analyze step as of Studio 9.1.

Graphs & Data	Selects which graph/data/image formats (see Sections 5.1 through 5.5) 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 Graph and Color Contour). As of Studio 9.1, these files can no longer be created but can be loaded from pre-existing files.
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 7.16 Image Annotations List

Common Z-Scale	When checked, causes the 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. Each Graph selected has its own Common Z-Scale selection.
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.

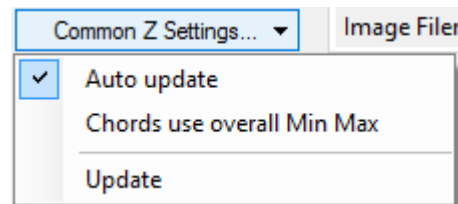


Figure 7.17 Common Z Settings

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 with the data files being available to are *.dat or *.txt.
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. Right-clicking into the Header box will bring up a context menu with Insert Metadata Tag selection displaying a list of available metadata to populate in this field. 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. Right-clicking into the Footer box will bring up a context menu with Insert Gauge Tag selection displaying a list of available gauges to populate in this field.
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. Options for the Phase Image, 2D Disp Image, and Surface Image can be selected by right-clicking on the respective data type. These options are explained below.

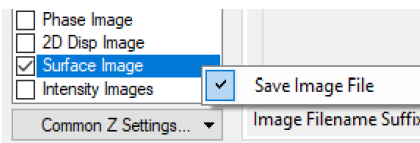


Figure 7.18 Surface Image Options

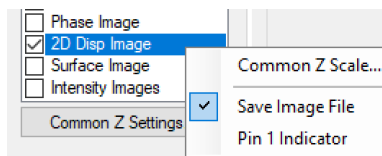


Figure 7.19 2D Disp Image Options

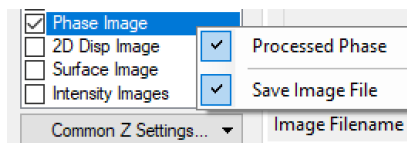


Figure 7.20 Phase Image Options

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. 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 and with or without an indicator to where the Pin 1 location is. Lastly, Surface Image files show the original image as seen by the camera at the time of capture and can be saved to disk or not.

7.1.5 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 7.21**. 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.

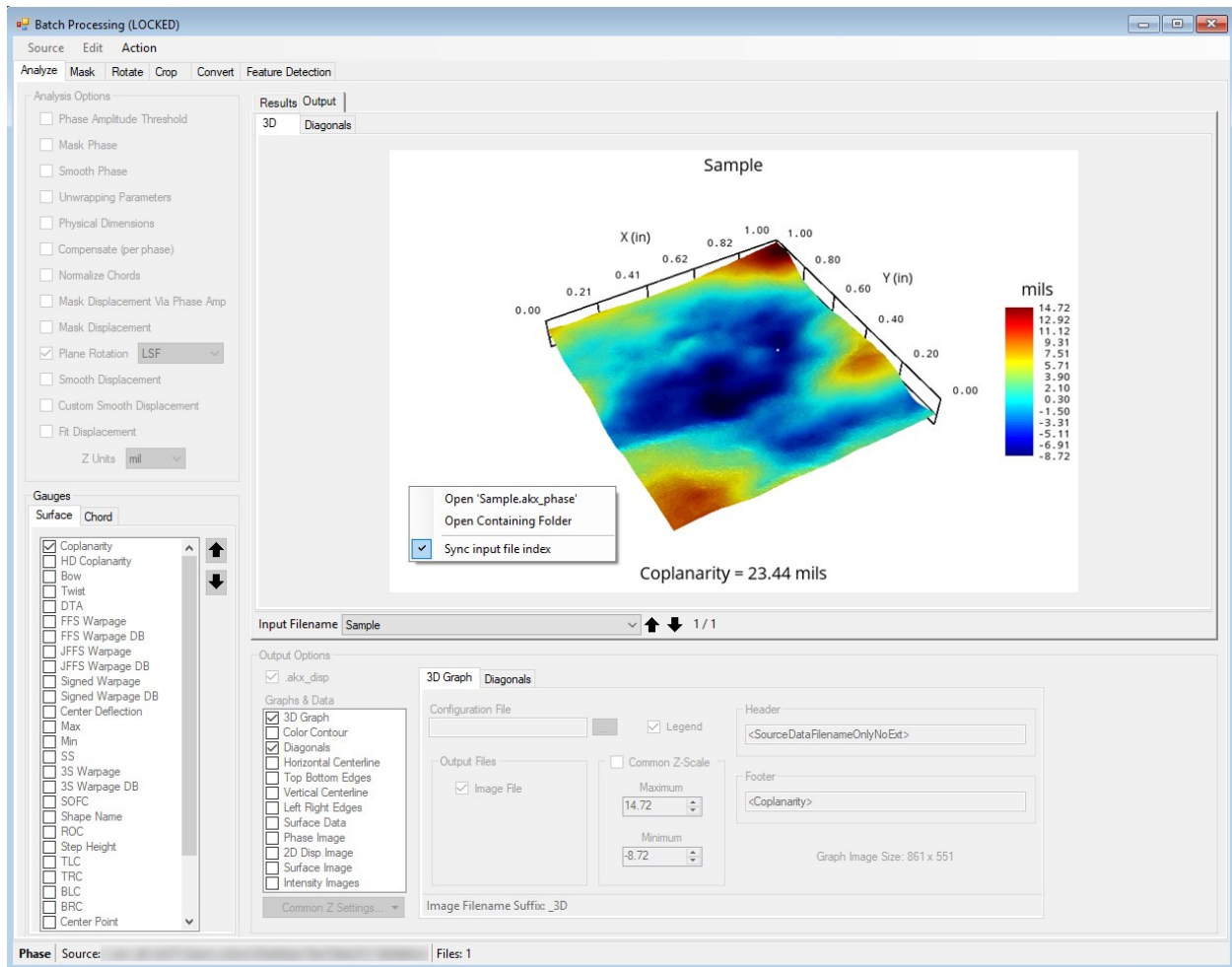


Figure 7.21 Output Tab

7.2 Batch Masking

The Batch Mask feature allows the user to automate mask-burning for multiple image files contained in a specified folder (Figure 7.22).

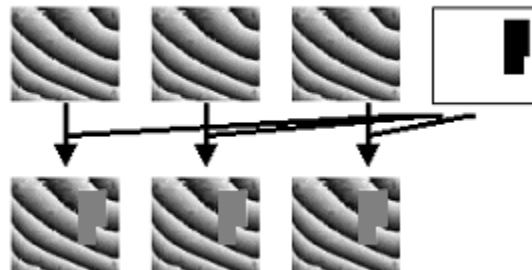


Figure 7.22 Batch Burn

7.2.1 Using Batch Masking

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.

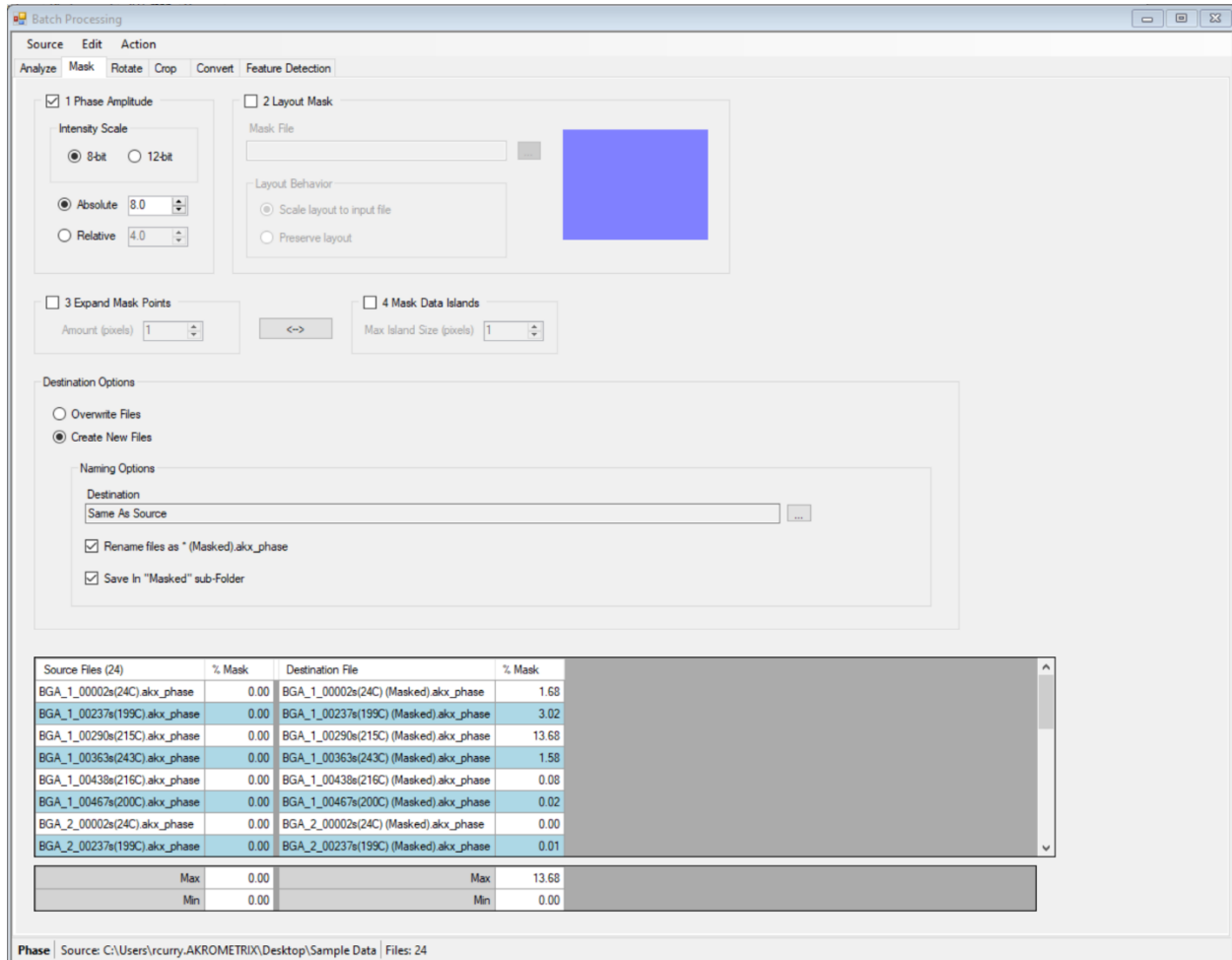


Figure 7.23 Batch Masking Screen

Layout Mask is the original region mask function. It uses a mask file, as described in **Section 3.1**. 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 3.2** for background)
4. If using Layout Mask, select a mask file (see **Section 3.1** 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 3.1.6** and **3.1.7**).
6. If using both, choose the order in which Expand Mask Points and Mask Data Islands occur (see **Section 7.2.7**).
7. Select destination options (**Section 7.2.8**)
8. Create and save results (**Action→Mask** menu item)

7.2.2 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 7.2.9).
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

7.2.3 Loading a Mask File

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

7.2.4 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.

7.2.5 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 3.1.6** for details on expanding mask points.

7.2.6 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.

7.2.7 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.

7.2.8 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.

7.2.9 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.

7.2.10 Masking Displacement Files

When masking *.akx_disp files in Batch Mask, several new options appear in the Batch Processing Window, as shown in **Figure 7.24**. 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 3.10**, 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. As of Studio 9.1, a $\pm 1, 2$, or 3 Sigma Z-Range is available. The $\pm$ Sigma Z-Range will filter data by the equivalent number of standard deviations of the total data range. To enter a specific number of microns to filter in the Z-Range of the files, in the same drop-down selection box choose the User Defined selection and enter the Max and Min value to be masked in the Range. For Percent mode enter the Max and Min percents in the Range section from 0 to 100%.

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.

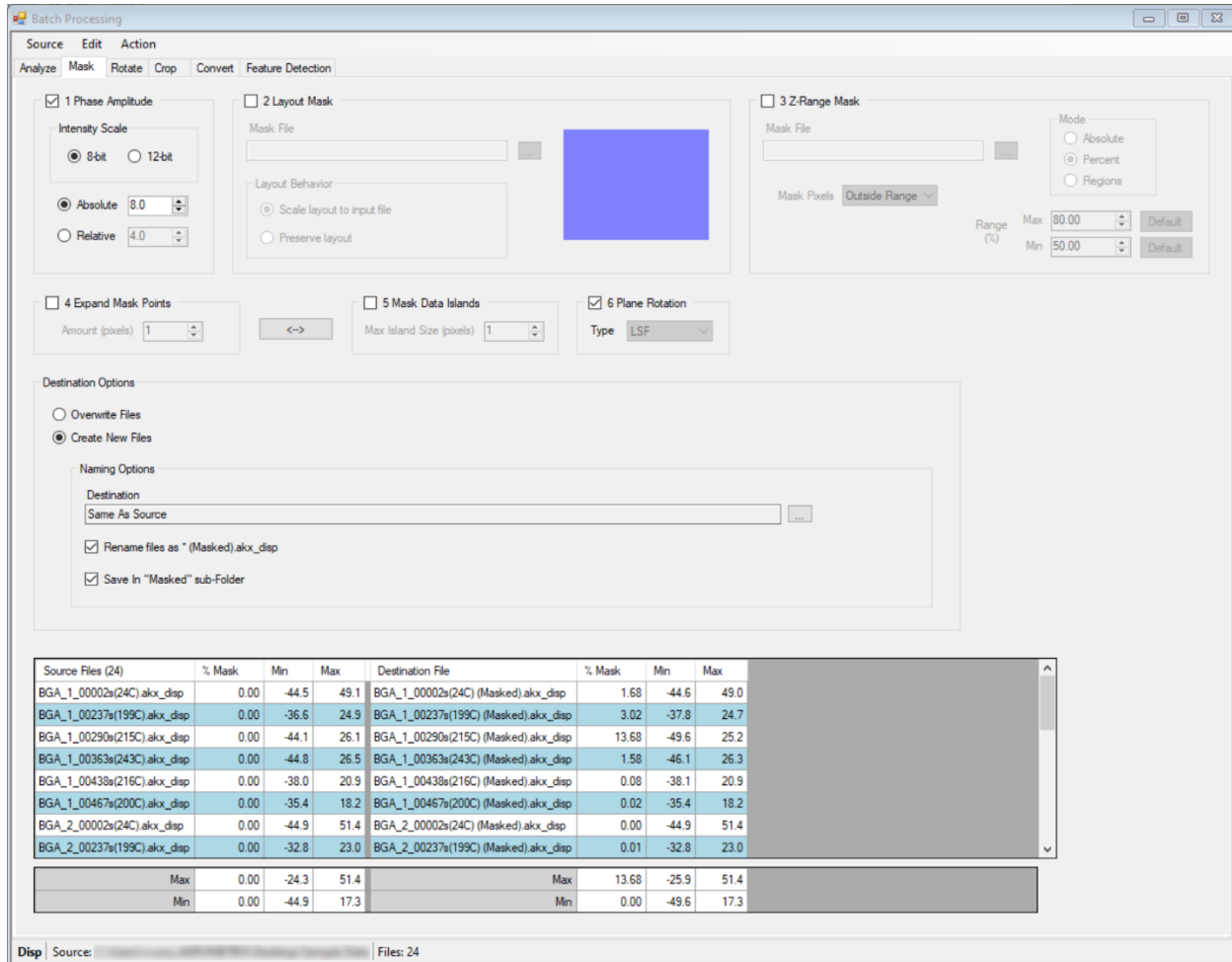


Figure 7.24 Batch Mask Results for Displacement Files

7.3 Batch Rotation

7.3.1 Using Batch Rotation

Phase image rotation is described in **Section 3.5** 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 7.25**.

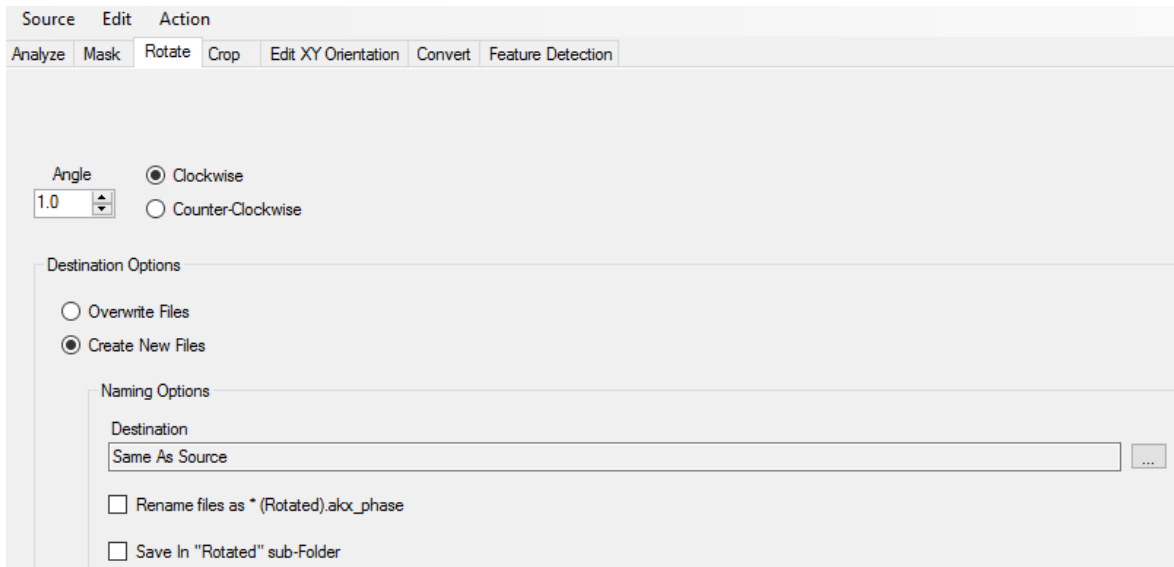


Figure 7.25 Batch Rotation Screen

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 7.3.2**)
3. Select destination options (see **Section 7.3.3**)
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.

7.3.2 Rotation Options

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

7.3.3 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.

7.4 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 ($3 \times 4 = 12$ measurements), can be easily analyzed in a two-step procedure: batch cropping, followed by batch analysis (**Figure 7.26**).

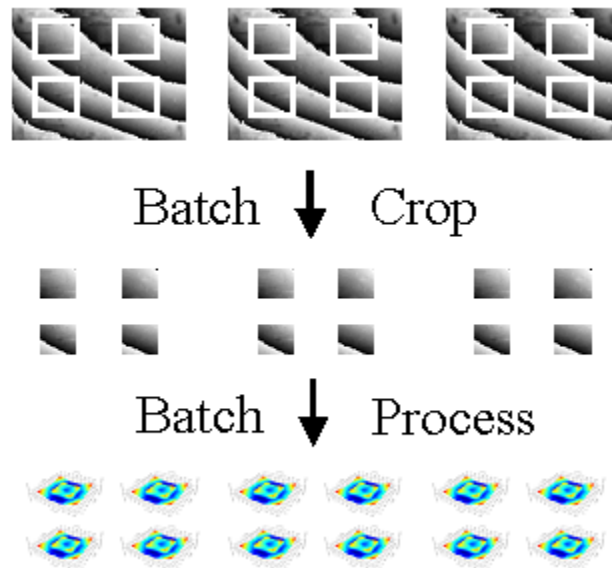


Figure 7.26 Batch Cropping and Analysis

7.4.1 Using Batch Cropping

The cropping mode can be changed by using the radio buttons at the top of the batch crop tab. There are two methods of cropping a file available on the Batch Crop tab: Crop To Extents and Partition.

Crop To Extents does not require a partition but otherwise uses the same process as partition cropping, including the creation of new, cropped files. 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 3.3.6** for a graphical illustration of how Crop To Extents works.

Partition cropping requires that the user has created a partition file as described in **Section 3.3**. 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 7.4.2**) 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 7.27**.

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 3.3.1** to create and save partitions) to be applied, or choose Crop To Extents.
3. Select destination options (**Section 7.4.3**)
4. Create and save results (**Action**→**Crop** menu item)

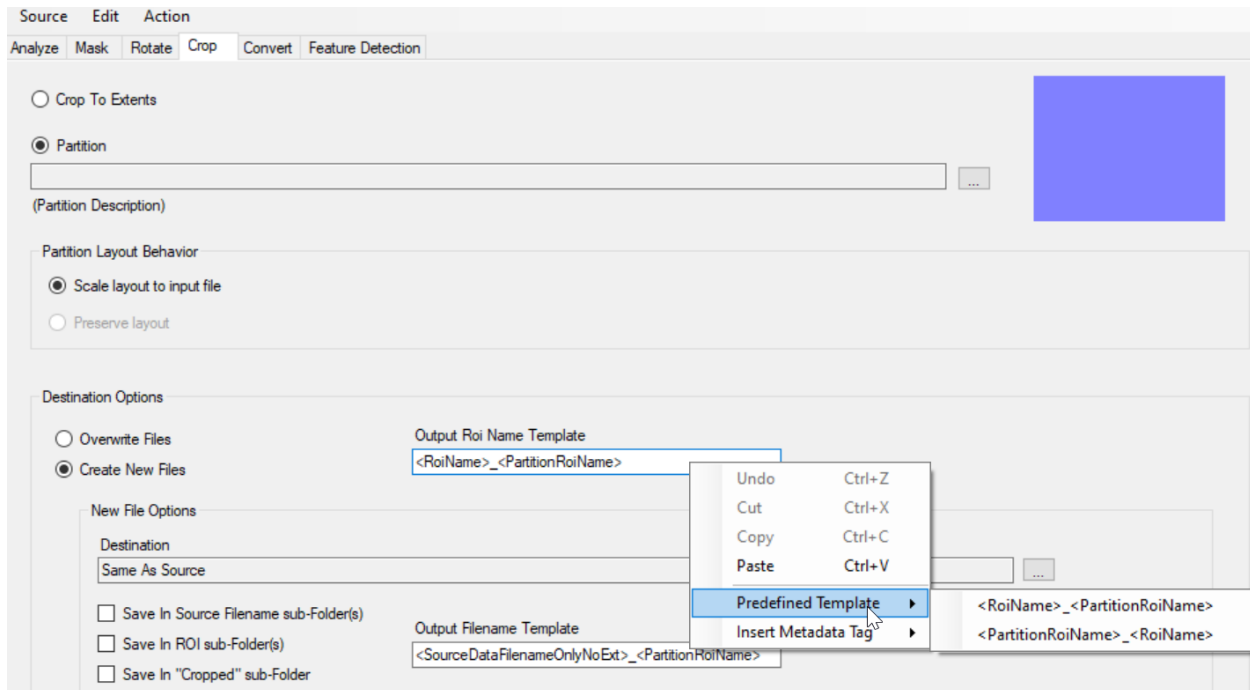


Figure 7.27 Batch Cropping Screen

7.4.2 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.

7.4.3 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. If this is selected only the first region in the partition file will be cropped.
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-Folder(s)	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.

7.5 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)

7.6 Batch Feature Detection

Batch Feature Detection allows the user to apply the Feature Detection function described in **Section 3.9** 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 7.28**.

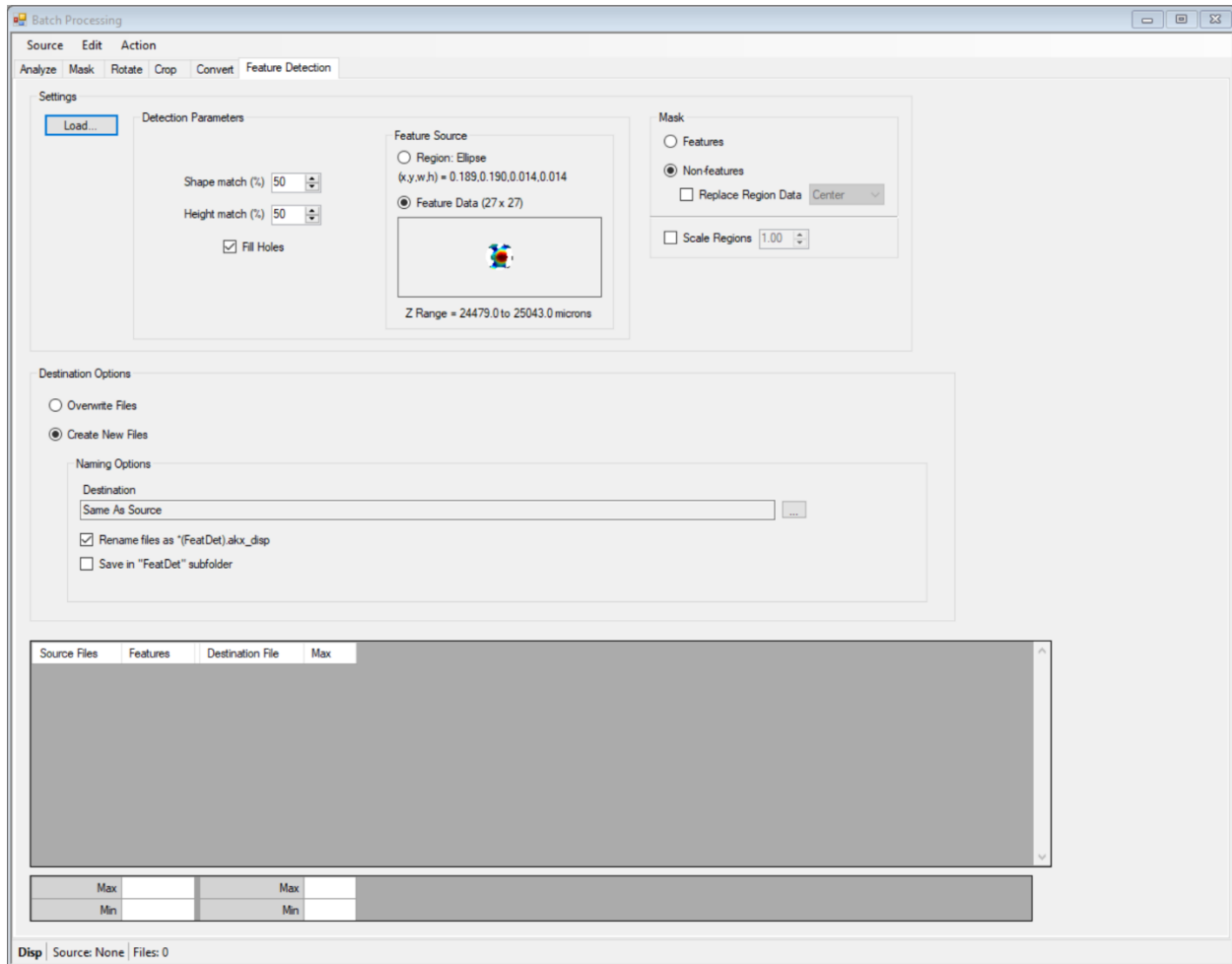


Figure 7.28 Batch Feature Detection Screen

7.6.1 Using Batch Feature Detection

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 7.6.2**).
3. Select destination options (see **Section 7.6.3**)
4. Create and save results (**Action**→**Detect Features** menu item)

5. View results in Results table (see **Section 7.6.4**).

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

7.6.2 Feature Detection Settings

These Settings are all identical to those in the Feature Detection Parameter Window, which is described in **Section 3.9**. 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.

7.6.3 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.

7.6.4 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 7.2.9**. 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 Automated Report Generator

Reports can be created using the metadata from each displacement file under analysis, as described in **Section A.1.1**. The Create Report window is divided into three subsections: **Groups**, **Roi Selector**, and **Layout Settings**. The **File** menu provides options to save and load report settings as an *.akx_ReportSettings file. When loading settings, the user may choose to load **Source Folders**, **Grouping Parameters**, and/or **Layout Settings** (**Figure 8.1**).

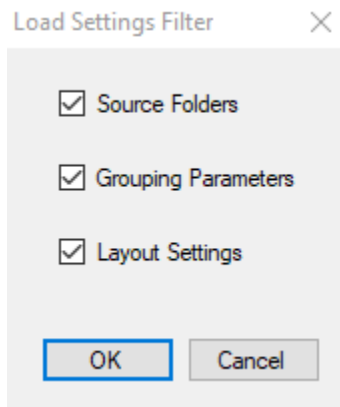


Figure 8.1 Load Report Settings Filter

Although reports are typically made for data taken over temperature, Surface Analysis also supports reporting for groups of room-temperature data. A radio button selection allows the user to switch between **Profile-based** and **Room Temp** modes.



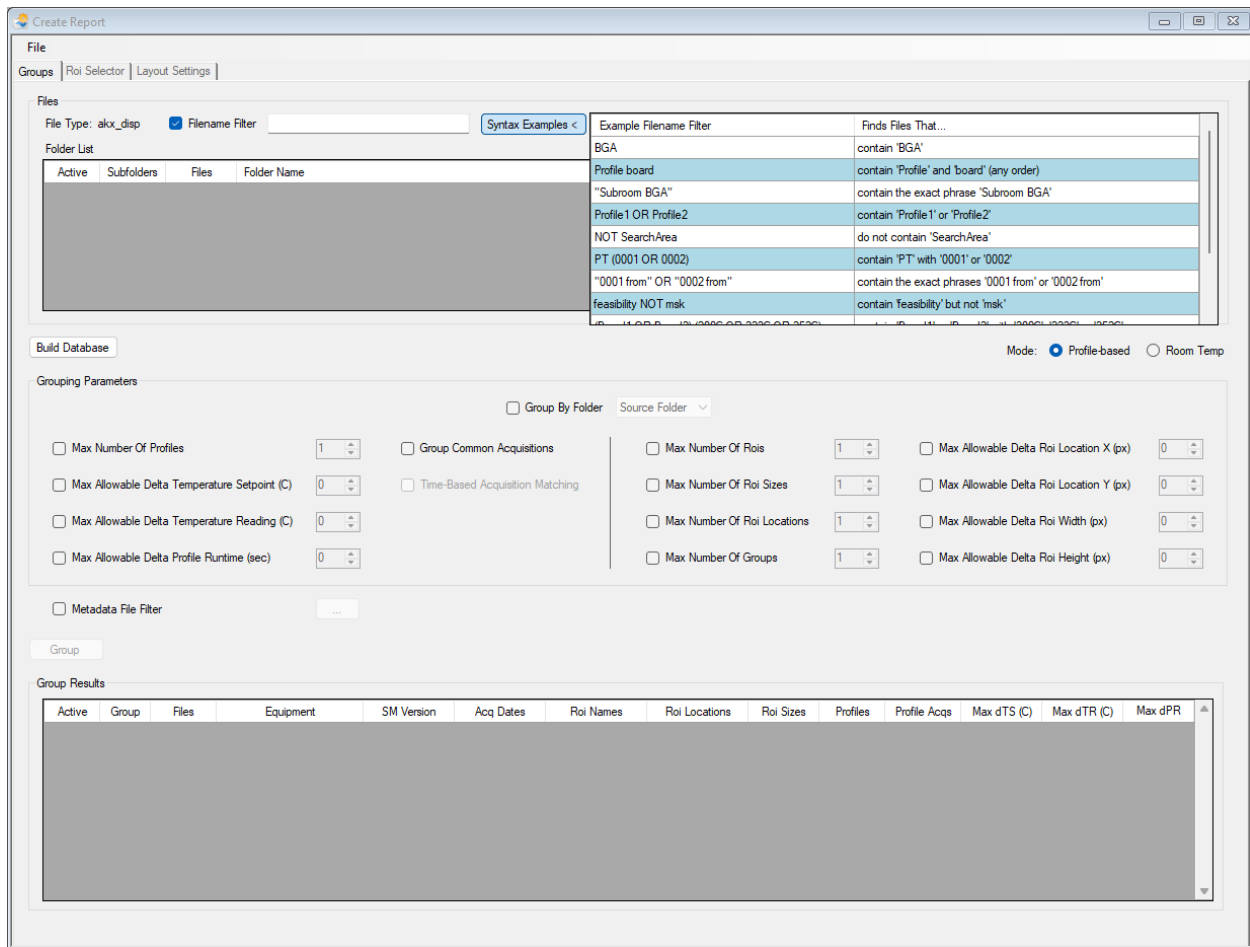
Note: The **Add file to profile...** function described in **Section 8.1.4** can be used to apply profile metadata to an orphaned measurement (typically a room temperature acquisition taken manually at the end of a profile).

8.1 Grouping by Metadata fields

Grouping can be performed either before or after analysis. For analysis, multiple folders can be selected. See **Section 7.1.1** for instructions on adding folders. The context menus in the **Folder List** area of the **Group** interface are identical to those used in the folder selection interface in Batch Analysis.



Note: If the Create Report function was opened from Batch Processing, the Folder List context menus initially appear as they do when no data is present, even though analyzed data has already been loaded. Additional folders can still be added and removed, but the analyzed data itself cannot be removed or set inactive in the Folder List.



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'

Figure 8.2 Create Report - Groups Tab



Note: When the “Room Temp” mode is selected, parameters related to temperature profiles are disabled.

8.1.1 Files

Once the appropriate folders have been added to the **Folder List**, files can be filtered out with search strings. The “*” character can be added before, after, or in the middle of a string to denote parts of the filename that do not need to match. Additional examples of supported search syntax are provided 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 required files have been loaded into the folder list, click **Build Database** to index them. After a database has been built, files are grouped by acquisition index. If the files must be separated into distinct report groups, one or more of the following Grouping Parameters may be applied.

8.1.2 Grouping Parameters

1. Group By Folder: Source Folder or Full Path.
 - a. Source Folder groups files by source folder name. Folders with the same name but located in different paths are combined into a single group.
 - b. Full Path groups by complete folder path, so each unique path forms a separate group.
2. Max Allowable Delta Temperature Setpoint (C): Specifies the maximum permitted difference in setpoint temperature. Files whose setpoint temperatures differ by no more than this value may still be grouped together. For common acquisition indices, the largest temperature difference is used for comparison.
3. Max Allowable Delta Temperature Reading (C): Specifies the maximum permitted difference in acquisition temperature. Files whose measured temperatures differ by no more than this value may still be grouped together. For common acquisition indices, the largest temperature difference is used for comparison.
4. Max Allowable Delta Profile Runtime (sec): Specifies the maximum permitted difference in acquisition time. Files whose acquisition times differ within this limit may still be grouped together. For common acquisition indices, 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 enabled. When enabled, the acquisition index is ignored during grouping and files are instead grouped by time, referencing Max Allowable Delta Profile Runtime (sec). This option could be used if comparing similar profiles in which one profile contains additional acquisitions.
6. Max Number Of Profiles: Specifies the maximum number of profiles permitted within a group.
7. Max Number Of Rois: Specifies the maximum number of Roi names permitted within a group.
8. Max Number Of Roi Sizes: Specifies the maximum number of ROI sizes permitted within a group.

9. Max Number Of Roi Locations: Specifies the maximum number of ROI locations permitted within a group.
10. Max Allowable Delta Roi Location X: Specifies the maximum permitted difference in ROI position along the X axis within a group.
11. Max Allowable Delta Roi Location Y: Specifies the maximum permitted difference in ROI position along the Y axis within a group.
12. Max Allowable Delta Roi Width: Specifies the maximum permitted difference in ROI width (along the X axis) within a group.
13. Max Allowable Delta Roi Height: Specifies the maximum permitted difference in ROI height (along the Y axis) within a group.
14. Group Common Acquisitions: When multiple profiles are reported together, and their acquisition indices do not fully align, this option removes orphaned acquisitions. In **Table 8.1**, the reported profiles have different numbers of acquisitions, and the first acquisition has been removed from Profile 2. When this option is enabled, only the acquisitions highlighted in yellow are included in the report.

Table 8.1 Group Common Acquisitions Example

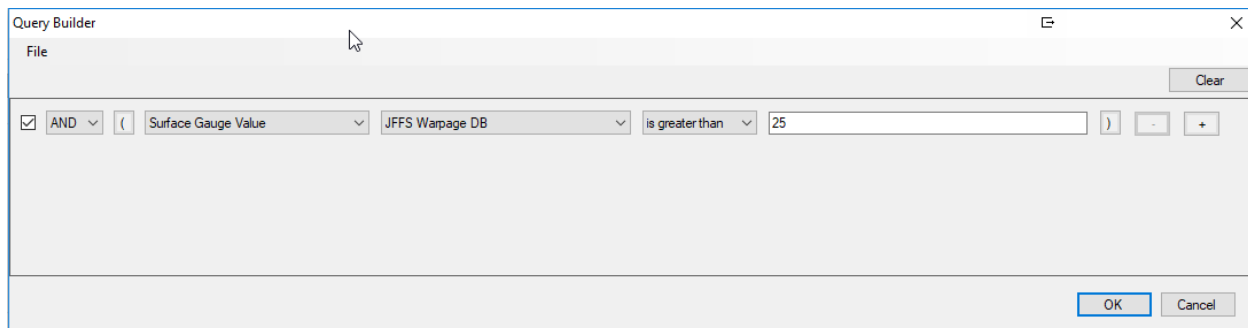
	Acquisition Index				
Profile 1	1	2	3	4	5
Profile 2		2	3		
Profile 3	1	2	3		



Note: If the effects of the grouping parameters are unclear, it is often helpful to test the settings and review the resulting output grouping directly.

8.1.3 Metadata File Filter

Files may also be excluded from resulting groups by defining filters and 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 8.3 Metadata File Filter Query Builder

Multiple logic conditions can be combined using AND/OR operators and parentheses to group sets of conditions. Conditions can be added or removed using the + and – buttons. Nearly 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

After the files have been indexed, all groups are shown in the **Group Results** section (**Figure 8.4**). This section lists key information about each group, including the number of files, the number of ROI names and locations, and the number of temperature profiles. Individual groups can be activated or deactivated here, allowing precise control over which ROIs are included in the final report.



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

Group Results													
Active	Group	Files (2)	Equipment	SM Version	Acq Dates	Roi Names	Roi Locations	Roi Sizes	Profiles	Profile Acqs	Max dTs (C)	Max dTa (C)	Max dt (s)
☒	1	2	S/N0001.CBF	7.7.0368	03/28/16	ROI	533.417	(2)	1	2	n/a	n/a	n/a
Edit metadata... Copy files to folder... Reassign file to new profile...													

Figure 8.4 Group Results

To change ROI names and other metadata for clear organization and labeling in the report, open the **Edit Group Metadata** window by right-clicking and selecting “Edit Metadata” from the context menu, or double-click on any group. (**Figure 8.4**).

Edit Group '1' Metadata											
akx_disp (14)	#	Profile	Acq Index	Temp Setpoint	Temp Nominal	Temp Reading	Pin 1 Location	Measured Side	Lot Id	Operator Id	Product Id
Region 001_Unit_00001s(25C)	1	1	1	25		25	Unspecified	Unspecified	asdf		
Region 001_Unit_00001s(25C)_mod	2	1	1	25		25	Unspecified	Unspecified			
Region 001_Unit_00261s(148C)	3	1	2	150			Unspecified	Unspecified			
Region 001_Unit_00261s(148C)_mod	4	1	2	150			Unspecified	Unspecified			
Region 001_Unit_00399s(215C)	5	1	3	217			Unspecified	Unspecified			
Region 001_Unit_00399s(215C)_mod	6	1	3	217			Unspecified	Unspecified			
Region 001_Unit_00488s(259C)	7	1	4	260			Unspecified	Unspecified			
Region 001_Unit_00488s(259C)_mod	8	1	4	260			Unspecified	Unspecified			
Region 001_Unit_00590s(219C)	9	1	5	217		219	Unspecified	Unspecified			
Region 001_Unit_00590s(219C)_mod	10	1	5	217		219	Unspecified	Unspecified			
Region 001_Unit_00745s(152C)	11	1	6	150		152	Unspecified	Unspecified			

Figure 8.5 Edit Group Metadata

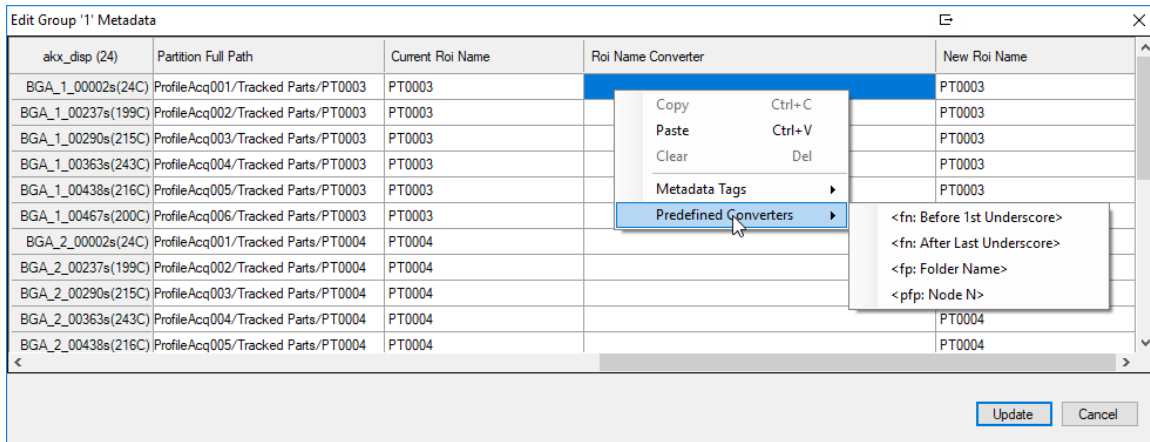


Figure 8.6 Edit Group Metadata - Roi Name Converter

In the Edit Group Metadata window that pops up (**Figure 8.5**), 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.

To modify an ROI Name enter a template string under the **ROI Name Converter** column. The template may combine fixed text with metadata references. To insert metadata, enter the field name inside angle brackets. For example, **<LotId>** would insert the Lot Id metadata value for that file. A list of available metadata tags is available via right-click context menu in the converter field. The same menu also provides several predefined functions as shown in **Figure 8.6**. The **<fn: Before 1st Underscore>** function provided creates a New Roi Name by parsing the input filename and using the string before the first underscore. Custom regex converters may also be used, as described in **Section 8.1.5**. The resulting ROI name, including the current values of any inserted tags, is displayed in the **New ROI Name** column.

Template strings may be copied and pasted into additional rows. Multiple rows may be selected using Shift-click, click-and-drag, or Ctrl-click, allowing values to be copied across several rows. Use Ctrl+C and Ctrl+V to copy and paste values. Use Ctrl+A to select all rows in a column for editing.



Note: Changes to file metadata are not applied until the **Update** button is clicked. If ROI names depend on metadata values that have just been modified, the metadata must first be updated, and the Edit Group Metadata window must then be reopened.

If a file does not contain profile information, it may be assigned to an existing profile from a right-click context menu in the Group Results section. (**Figure 8.7**). This is commonly used for manually acquired data collected after a profile has ended. If multiple

orphaned files are present, selecting **Add file to profile...** will open a file selection dialog (**Figure 8.8**). The user must then select the destination profile (**Figure 8.9**). After the profile is selected, the **Setpoint**, **Temp Reading**, **Profile Runtime**, and **Acquisition Index** may be added to that file's metadata. The modified file may also be renamed. Once the profile data for a file has been updated, the file is automatically moved to the appropriate group (**Figure 8.10**).

If a file is assigned to an incorrect profile, it can be reassigned using the same procedure.

Group Results

Active	Group	Files (8)	Equipment	SM Version	Acq Dates	Roi Names	Roi Locations	Roi Sizes	Profiles	Profile Acqs	Max dTs (C)	Max dTa (C)	Max dt (s)
☒	1	6	S/N0194 TherMoire AXP	8.1.10491	03/29/17	(2)	(2)	611 x 134	1	3	n/a	n/a	n/a
☒	2	2	S/N0194 TherMoire AXP	8.1.10491	03/29/17	(2)	(2)	611 x 134	n/a	n/a	n/a	n/a	n/a

Context Menu for Orphaned Files:

- Edit metadata...
- Copy files to folder...
- Add file to profile...

Figure 8.7 Group Results - Context Menu for Orphaned Files

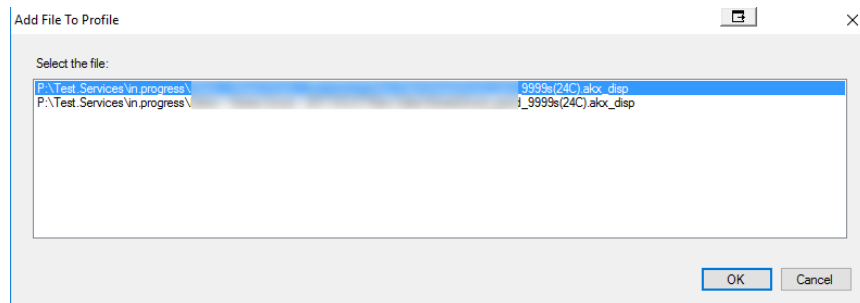


Figure 8.8 Add File to Profile - File Selector

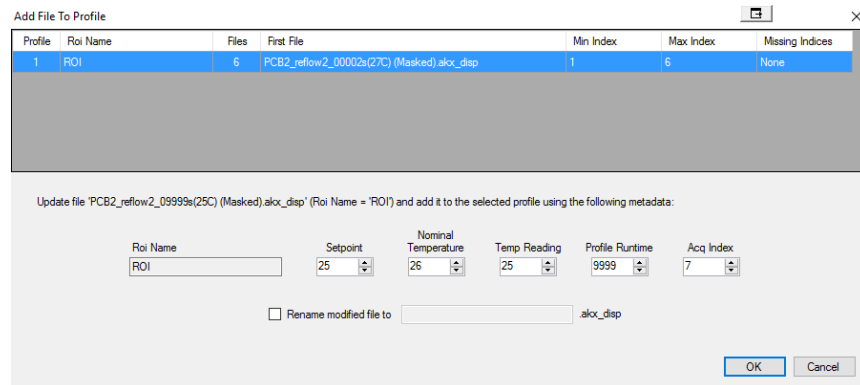


Figure 8.9 Add File to Profile - Profile Selector

Group Results

Active	Group	Files (8)	Equipment	SM Version	Acq Dates	Roi Names	Roi Locations	Roi Sizes	Profiles	Profile Acqs	Max dTs (C)	Max dTa (C)	Max dt (s)
☒	1	8	S/N0194 TherMoire AXP	8.1.10491	03/29/17	(2)	(4)	611 x 134	1	4	n/a	n/a	n/a

Figure 8.10 Group Results after Adding Files to Profile

8.1.5 Custom Converters

Figure 8.11 shows several custom regex converters, which simplify extraction of specific character sequences from a filename and support more flexible ROI naming in the Edit Metadata window. The specific rules followed by custom converters are shown below.

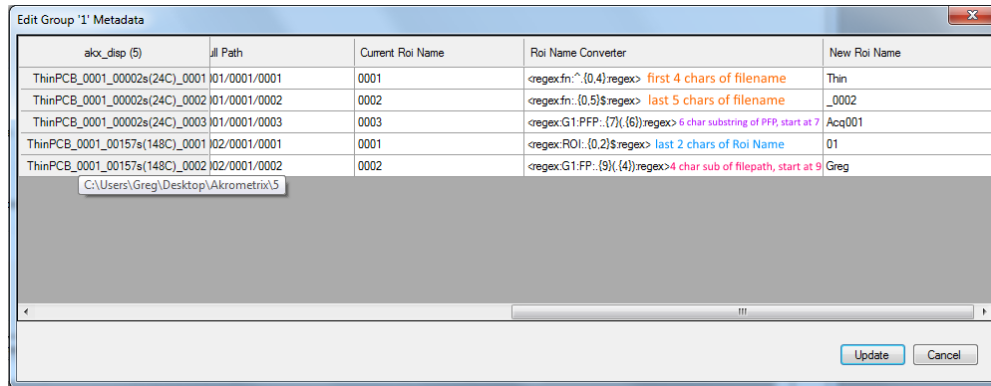


Figure 8.11 Custom Regex Converters

- Custom converters begin with **<regex:** and end with **:regex>**
- Custom converters can optionally include a 'Group Index' specifier, which may be required to get the desired regex match
 - If no Group Index is specified, group index is 0 (default).
 - Group Index is the first item included inside the regex syntax, and ends with a colon, specified as **G#:** or **G##:**
- Custom converters can operate on 1 of 4 sources (specifiers are NOT case-sensitive): a colon is required after the source
 - Filename, specified as **FN**
 - Filepath (entire path, not including the filename), specified as **FP**
 - Partition Full Path, specified as **PFP**
 - Roi Name, specified as **ROI**
- The regex expression is supplied AFTER the source colon.
- Examples:
 - <regex:fn:^(0,4):regex>** the first 4 characters of the filename
 - <regex:fn:.(0,5)\$:regex>** the last 5 characters of the filename
 - <regex:G1:PFP:.(7)(.6):regex>** a 6 character long substring of the partition full path, starting at index 7
 - <regex:ROI:.(0,2)\$:regex>** the last two characters of the Roi Name
 - <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 8.12) 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.

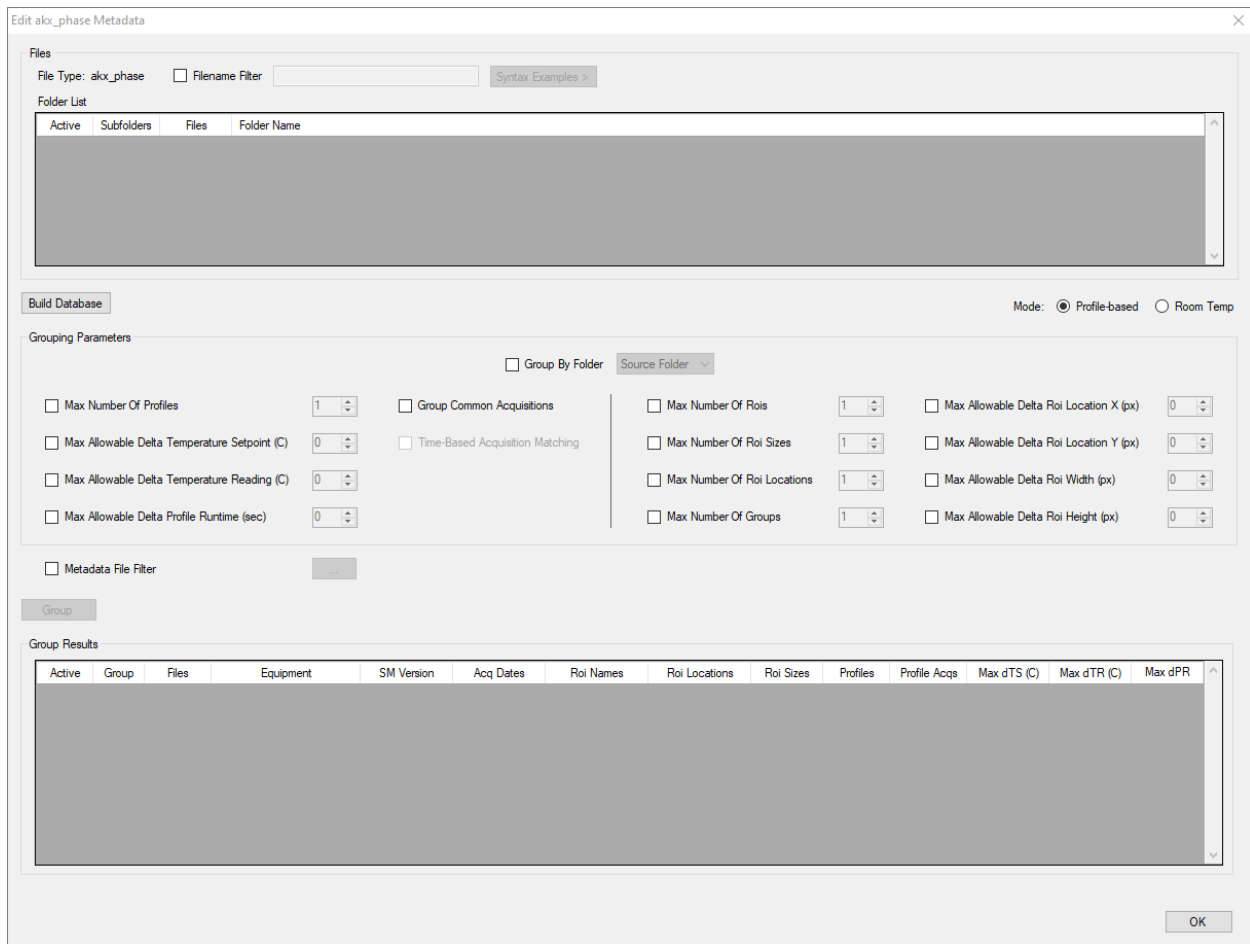


Figure 8.12 Edit akx_phase Metadata

8.2 Selecting ROIs

The **Roi Selector** tab (Figure 8.13) displays 3D graph thumbnails of all active files, organized into tabs by group. Use this tab to quickly review the data, identify the minima and maxima, both overall and in each group, and exclude bad data before generating a report.

Left-clicking on individual ROI thumbnails will exclude or include that data file from the report. Files that are excluded will be highlighted in a dark grey color. Similarly, entire rows or columns can also be removed from the report by clicking on the row or column header. Any highlighted files will turn to a grayscale color scheme after the **Update** button is pressed or by clicking off the Roi Selector tab.

Right-clicking any thumbnail brings up a context menu (Figure 8.13) with the following options. Open the selected *.akx_disp file or the folder containing that file. Files can also be included or removed en masse using **Include All**, **Include None**, **Invert Included**, and **Include via metadata query...** commands.

The controls at the bottom of this window affect only the display within the Roi Selector tab. These include changing the thumbnail size, Common Z Scale, and Z Unit. Click the **Update** button to apply any changes made to these settings.

The Common Z Scale drop-down controls whether 3D graph 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.

For each Group tab, the minimum and maximum values are displayed automatically. The corresponding thumbnails are highlighted in purple: dark purple for the minimum and light purple for the maximum.

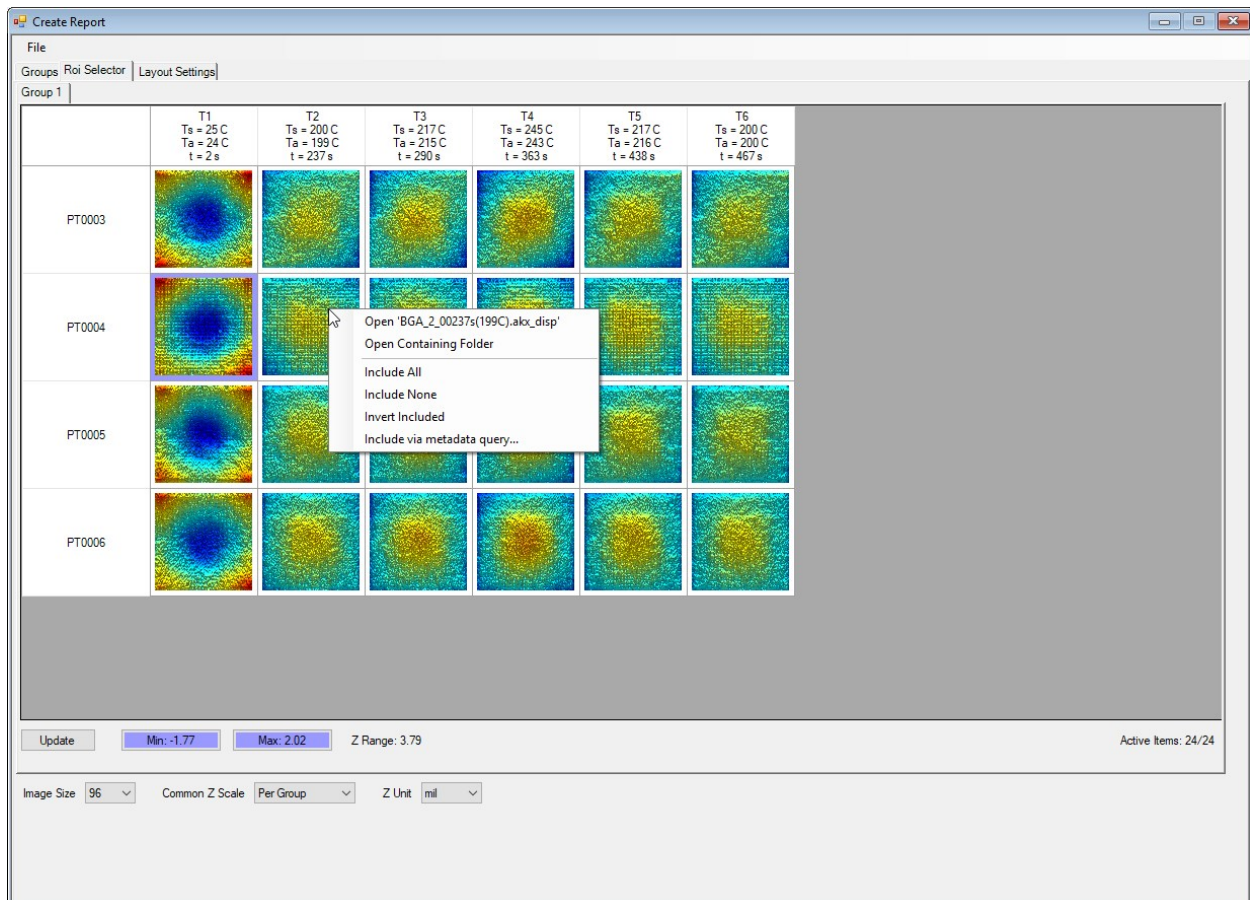


Figure 8.13 Create Report - Roi Selector Tab

8.3 Layout Settings

After the ROIs have been organized into groups and unwanted data has been excluded, use the Layout Settings tab to define the format and displayed content of the report. Groups can also be deactivated here without changing other settings, making it simple to create either combined reports or separate reports for individual groups.

The report content and format settings are divided into the following subsections.

8.3.1 Group and Plot Selection

The upper section of the Layout Settings tab provides options for reviewing and organizing report groups. Users can choose which groups to include in a report by selecting the Active checkboxes. The table also displays details for each group, including the group number, Z-Range, number of files, and the name of the first file in the group.

Hovering over certain cells displays additional information in a tooltip. For example, tooltips may show the full list of ROI names or the gauge plots currently selected for that group.

This section also includes several editable labels that can appear in the report. These can be used for image titles, series labels in Gauge vs Temperature plots, page titles, subtitles, and footers. Metadata tags like <RoiName> and <PageGraphType> may be inserted into these fields. Labels appear only on pages with data for the selected group, and the report will automatically separate groups into different sections.

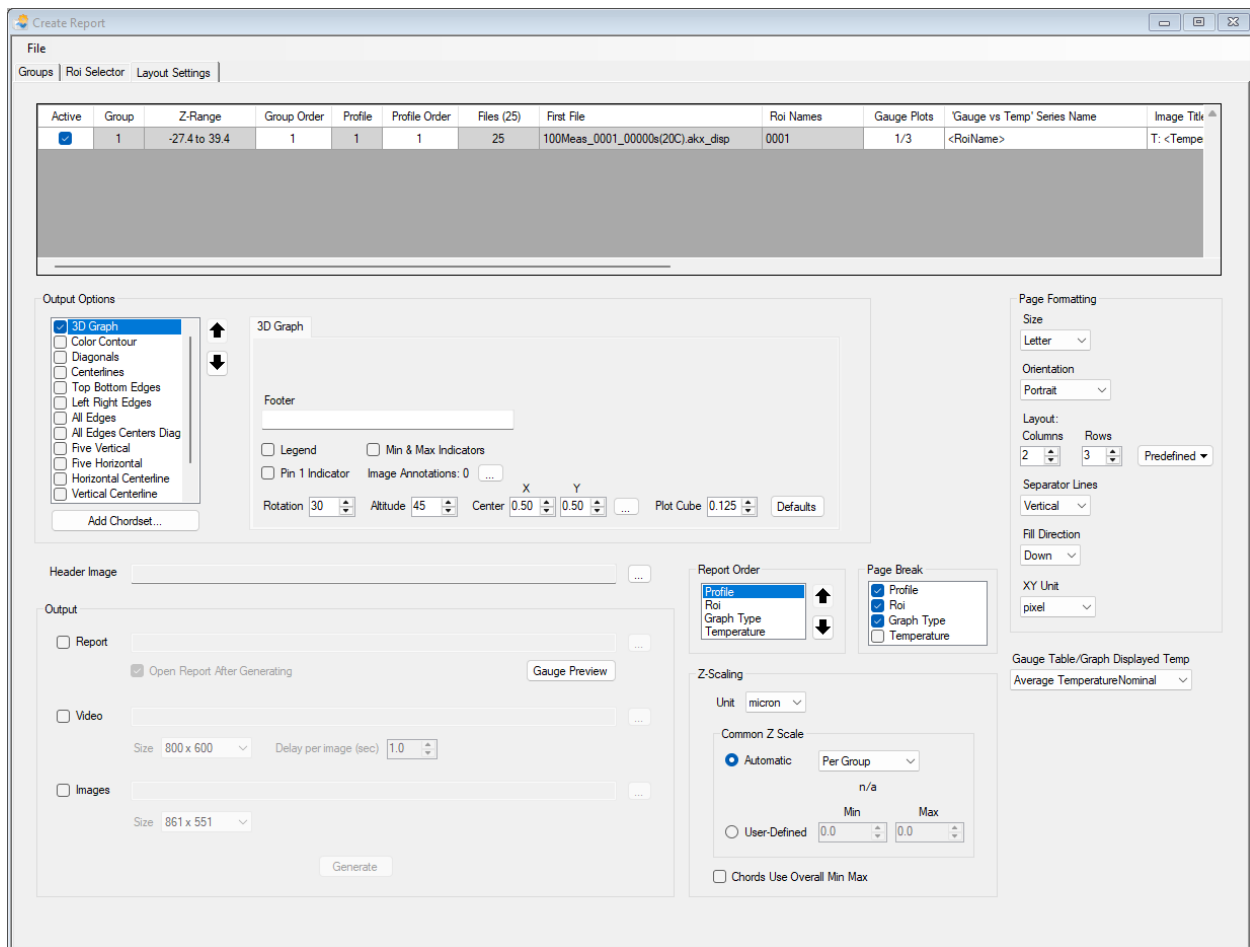


Figure 8.14 Create Report - Layout Settings Tab

Click the Gauge Plots cell for a group to open the **Gauge Plot Selector** window (Figure 8.15). In this window, users select which calculated gauges will appear in the report and which statistical values will be included for each gauge. Statistics can be calculated at several levels, including per ROI, per temperature point, and globally across

the full group. Gauge plot order can also be changed here by selecting an item and using the arrow controls to move it up or down in the list.



Note: If a desired gauge is not in this list, then it was not calculated during analysis. In Batch Processing, any gauges needed in the report must be selected during analysis so that they are embedded in the *.akx_disp files used to build the report.

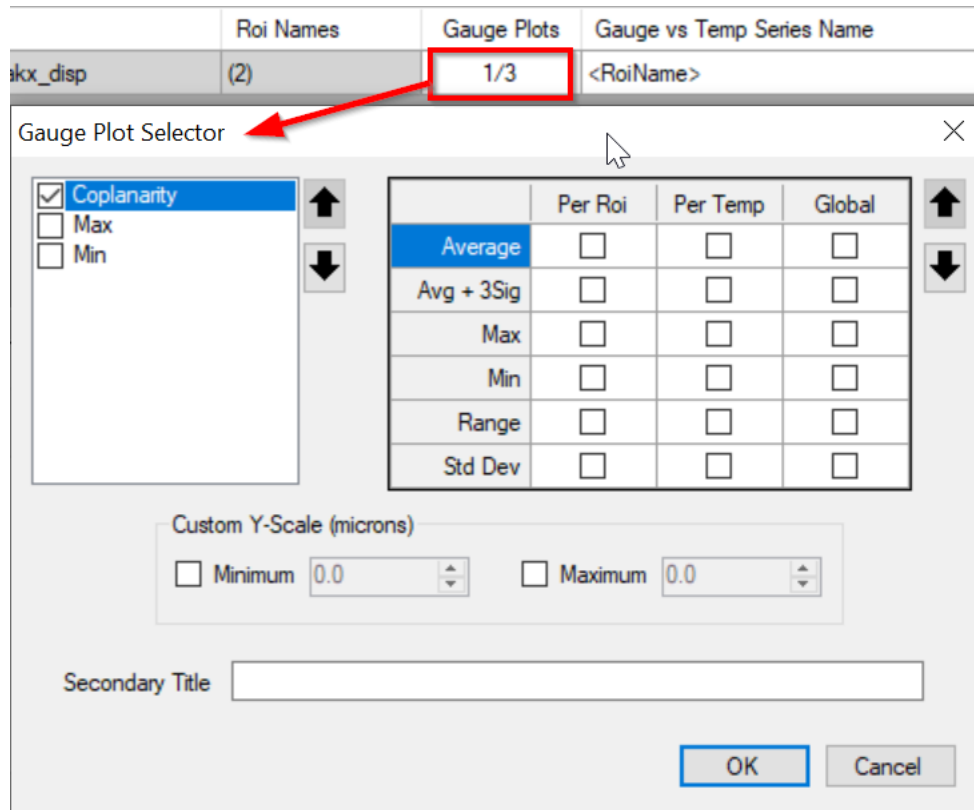


Figure 8.15 Gauge Plot Selector

8.3.2 Output Options

This section allows the user to decide which graphs will be shown in the report, how they are configured, and what footer information the graphs will include. It also provides options for displaying min and max value indicators, Pin 1 location indicators, individual legends, and 3D plot view point and center. The ratio of x/y scale to z scale in the 3D plot can be altered with the Plot Cube setting. In 2D chord tabs, a normalized option is available (endpoints referenced to zero). Image Annotations can be added as described in **Section 7.1.4**.

Footer content is selected from a list of tags that changes based on the graph type. The user may also use tab (\t) and new line (\n) tags to format footer text in the report. As of Studio 9.1 the default separator between multiple tags is tab (\t) instead of new line (\n).



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 setting determines the ordering priority within a group. The default is **Profile > ROI > Graph Type > Temperature**. In 'Room Temp' mode, the order changes to **Acquire Timestamp > ROI > Graph Type**.

Table 8.2 shows a simple example using two graph types and 3 temperatures. When **Graph Type** is ordered before **Temperature**, all temperatures for a graph type are displayed together. When **Temperature** is ordered before **Graph Type**, all graph types for a temperature are displayed together.

Table 8.2 Report Order Behavior

Graph Type > Temperature	Temperature > Graph Type
Displacement @ 25°C	Displacement @ 25°C
Displacement @ 125°C	Chord @ 25°C
Displacement @ 250°C	Displacement @ 125°C
Chord @ 25°C	Chord @ 125°C
Chord @ 125°C	Displacement @ 250°C
Chord @ 250°C	Chord @ 250°C

8.3.4 Page Break

This setting determines where page breaks occur in the report. 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.



Note: Changes to **Report Order** often require corresponding changes to **Page Break** settings. After modifying either setting, generate the report and review the output to confirm that the pages are grouped and ordered as intended.

8.3.5 Z-Scaling

This section controls the Z-scale use for displacement graphs and Chord Graphs. They can change the Z units and choose either a custom Z-scale or 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 their own 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 number of columns and rows for plot pages. Predefined options for 6/page or 24/page
4. Separator Lines – Show lines separating plots. Options are None, Horizontal, Vertical, or Both
5. Fill Direction – Determines whether plots are populated top-bottom and then left-right, or vice versa.
6. XY Unit – Sets the XY units displayed on each graph. When lateral resolution is defined for a file, the XY axes can be displayed in physical units instead of pixels.



Note: If a physical unit is selected but lateral resolution is not defined for a file, graphs generated from that file will display XY values in pixels.

8.3.7 Gauge Table/Graph Displayed Temp

This setting determines which temperature value is displayed in the gauge plots and gauge tables. The available options are average temperature reading, average nominal temperature, or average setpoint temperature.

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 Output section determines what results will be generated. There are three possible types of output – Report, Video, and Images – the selected outputs will be generated simultaneously when pressing **Generate**.

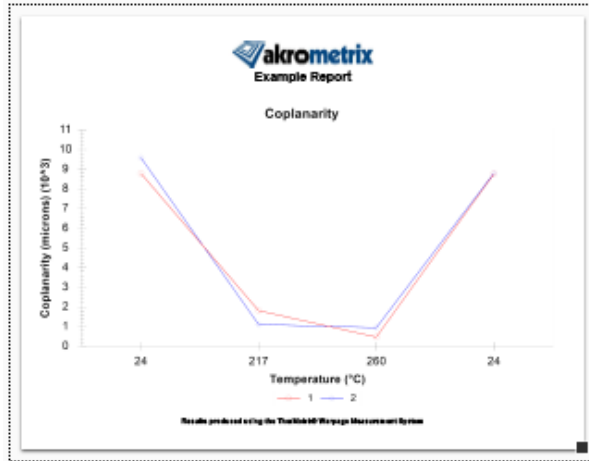
When an output option is selected, the user will be prompted to set the filename and destination folder. For Images, only a destination folder is needed. The first time that a filename or destination folder is entered, it will be shared to the other outputs. The ... buttons after each option can be used to independently edit destinations and filenames for each output.

1. **Report** – This option creates a pdf or rtf (rich text format) report containing all selected images and gauges. Most settings in the Layout Settings tab apply to this report rather than to video or image output. **Figure 8.16** 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, without images. Because images are not included, it provides a faster way to review group organization and overall numerical results. It can be used whether or not Report is selected as an active output.
3. **Video** – This option creates a video file containing all gauge plots and selected images in sequence. The user can specify the image size and the delay between images.

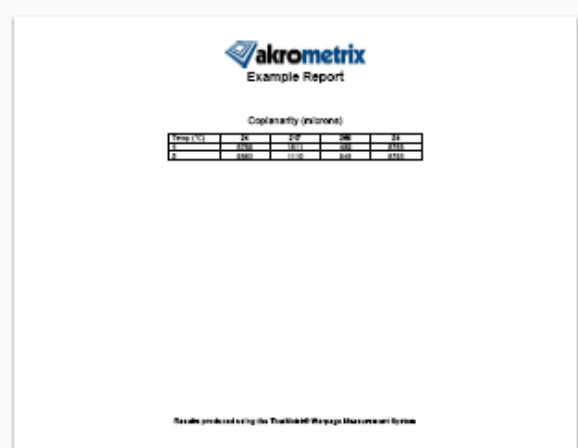
4. **Images** – This option saves all images selected in Output Options to a user selected folder. The image size can be specified and files are named according to the location they occupy, or would occupy, in the report, using the format PageXXX_ImageXXX.



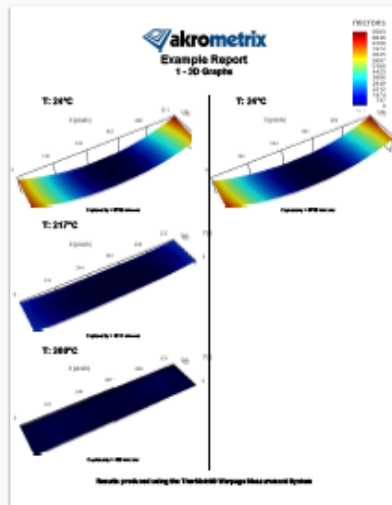
Note: Studio 9.1 now applies the footer on the output images and videos.



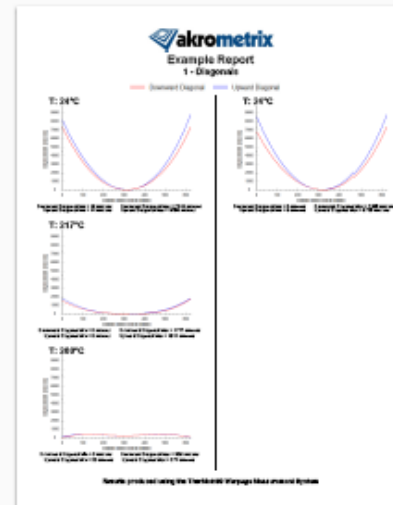
1



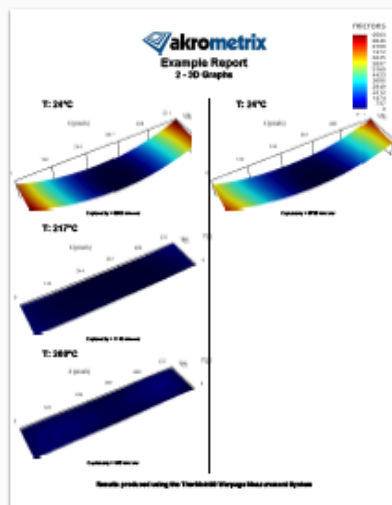
2



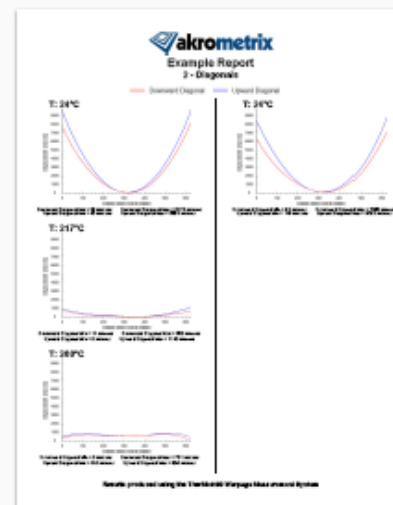
3



4



5



6

Figure 8.16 Example Report with 6 images per page

9 Batch Interface Analysis

Batch Interface Analysis is available from the **Tools** menu. It is used to analyze multiple pairs of displacement files and to generate multi-page reports in a manner similar to Batch Reporting (Section Error! Reference source not found.).

9.1 Groups Tab

Folders containing displacement files (*.akx_disp) are added to the folder list via a right-click context menu (Figure 9.1) or by dragging them from a File Explorer window.

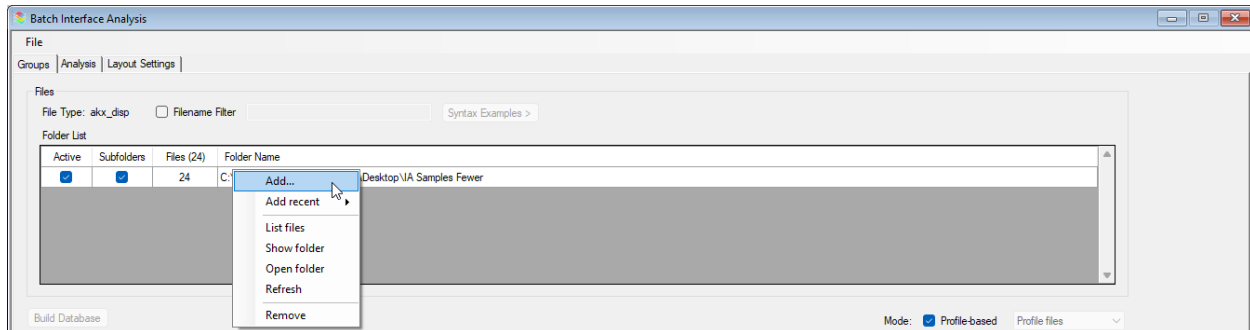


Figure 9.1 Batch Interface Analysis Add Folder Context Menu

As of Studio 9.1, A **Mode** selection allows the analysis to be based on temperature profiles or not. When **Profile-based** is not checked, a dropdown selection allows filtering of files in the input folders based on whether they were captured during a thermal profile or not. After the input mode is determined, **Build Database** compiles the file contents and **Group Results** are shown in two tables (Figure 9.2). 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 must be updated before it can be included in the analysis. These metadata fields can be updated from the right-click context menu, as in **Batch Reporting** (Section 8.1.4), or by double-clicking a group row in **Group Results** to open the **Edit Metadata** window (Figure 9.2).

Group Results														
Group	Files (24)	Equipment	SM Version	Acq Dates	Roi Names	Roi Locations	Roi Sizes	Pin 1 Location	Measured Side	Profiles	Profile Acqs	Max dTS (C)	Max dTR (C)	Max dPR
Bottoms	12	SN0194 TherMoire AXP	6.2.1	03/28/12	(4)	(9)	54 x 54	Upper Left	Inner	1	12 [9]	n/a	n/a	n/a
Tops	11	SN0194 TherMoire AXP	6.2.1	03/29/12	(4)	(8)	54 x 54	Upper Right	Inner	1	8 [9]	n/a	n/a	n/a
Unspecified	1	SN0194 TherMoire AXP	6.2.1	03/29/12	1	621.387	54 x 54	Upper Right	Unspecified	1	1 [2]	n/a	n/a	n/a

Active	Acq Index	Files (23)	Tops	Bottoms	Equipment	SM Version	Acq Dates	Roi Names	Roi Locations	Roi Sizes	Profiles	Profile Acqs	Max dTS (C)	Max dTR (C)	Max dPR
☒	2	7	3	4	SN0194 TherMoire AXP	6.2.1	(2) [1 day]	(4)	(7)	54 x 54	2	(7)	0	0	1
☒	3	8	4	4	SN0194 TherMoire AXP	6.2.1	(2) [1 day]	(4)	(8)	54 x 54	2	(8)	0	0	3
☒	9	8	4	4	SN0194 TherMoire AXP	6.2.1	(2) [1 day]	(4)	(8)	54 x 54	2	(8)	4	4	0

Figure 9.2 Batch Interface Analysis Group Results

Input files can be grouped by **Acquisition Index**, **Temperature Nominal**, or **Acquisition Order** metadata fields.

9.2 Analysis Tab

Once grouping is complete, the **Analysis** tab can be selected to configure analysis options. Under **Data Processing**, two primary analysis methods are available: **All**

Individual Combinations and **Statistical Surfaces**. **All Individual Combinations** analyzes every possible top and bottom surface pairing within each group. **Statistical Surfaces** combine the tops and bottoms within a group into representative surfaces for comparison. The different surface types and how they are calculated are described in **Section 9.4**.

If **Mix Combinations** is selected, different statistical surfaces can be calculated for top and bottom surfaces, although this is not typically used. Statistical Surfaces can also be saved as displacement files for review as individual surfaces. Additionally, the Gap Data can be saved as *.dat files, and the physical dimensions of the surfaces specified.

The remaining options in this area correspond to those available in **One-Off Interface Analysis (Section 6.3)**. After these settings have been selected, the analysis is run by pressing the **Analyze** button in the lower-left corner of the window. A preview of the results is shown to the right.

Results for either **Statistical Surface** pairings or **Individual Combinations** can be displayed by selecting the surface type from the drop-down menu, entering specific **Top** or **Bottom** surface indices, or clicking in a pairing column in the table below based on how the surfaces were grouped. A right-click context menu is available on both **3D** and **Chord** graphs with options that are largely the same as those available in the context menu for a **One-Off Interface Analysis** result window (**Figure 6.11**). In addition, the chord graphs section can be hidden in this context menu (**Figure 9.3**).

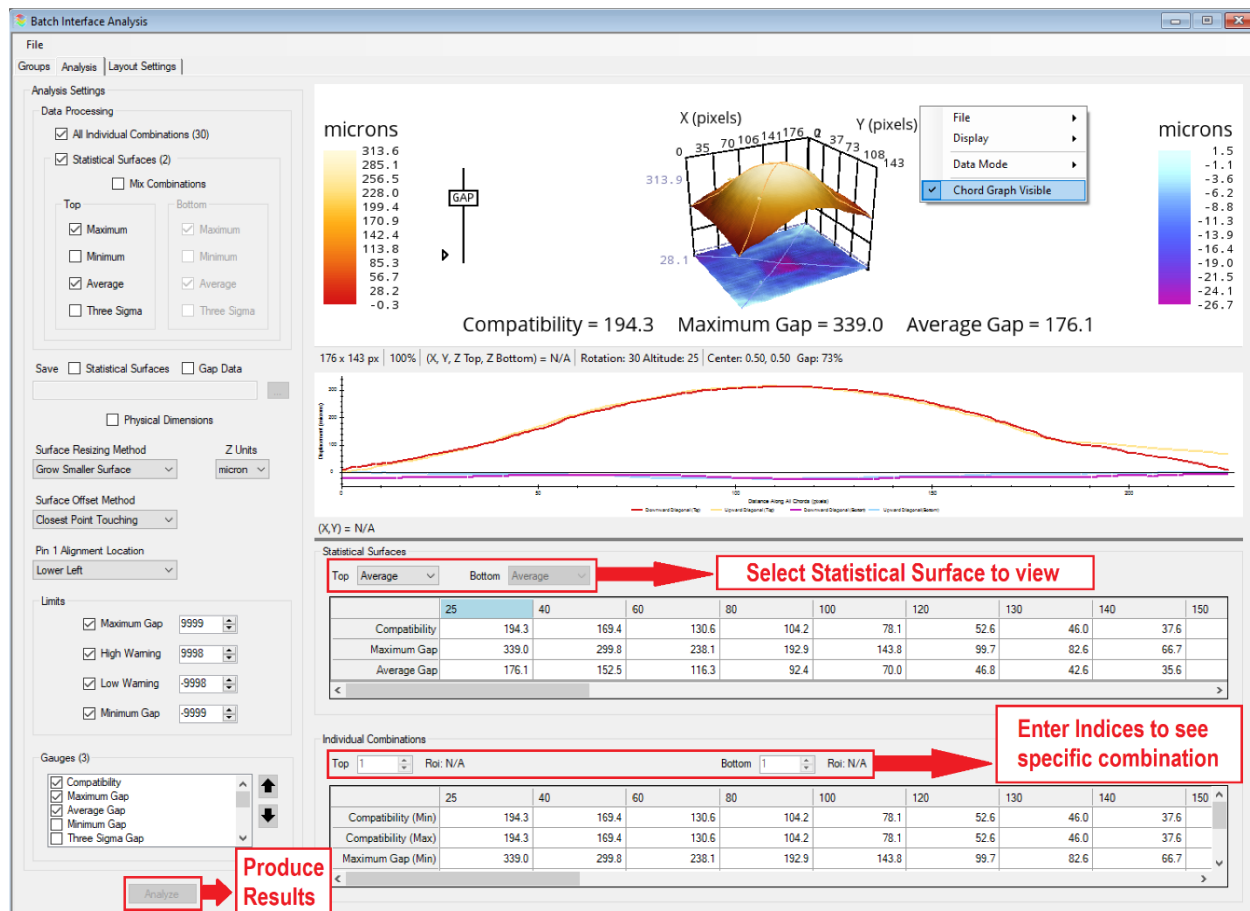


Figure 9.3 Batch IA Analysis Tab Results Preview

9.3 Layout Settings Tab

Once all the input data has been analyzed, the report layout can be configured on the **Layout Settings** tab (Figure 9.4). Three main options are available, depending on selections made during analysis: **Statistical Surfaces**, **Individual Pairings Gauge Extrema**, and **Individual Pairings**. If a given option was not included during analysis, the corresponding section will not be available.

Statistical Surfaces are discussed in Section 9.4. **Individual Pairings** displays all possible surface combinations. **Individual Pairings Gauge Extrema** displays the specific surface pairs associated with the selected gauge extrema. The gauge extrema available for display are the minimum or maximum of **Compatibility**, **Maximum Gap**, or **Average Gap**.

Page titles, subtitles, and image titles can be entered using either static text or metadata tags just as in Batch Reporting. Metadata tags are discussed further in Section A.1.1.

Below the three main surface options are the **Data Graphs** options. These can be selected from either a **Top/Bottom** or **Gap** mode like those from One-Off Interface Analysis. Gauges can be added to graph footers using tags. A **Pin 1 indicator**, **Image Annotations**, **Z-Legend**, or **Min & Max Indicators** can be added. A number showing in

parenthesis next to the **Data Graphs** checkbox indicates the total number of graphs that will be produced with the given Data Graphs selection.

The **Display Appearance...** dialog allows the 3D Graph or Gap plot appearance to be configured, similar to the Settings Panel interface in One-off Interface Analysis. The surfaces can be displayed with or without a wireframe as Solid, Transparent, or None. The gap distance for visualization purposes can be altered, and the PWF map enabled if Gap and Warning Limits have been set.

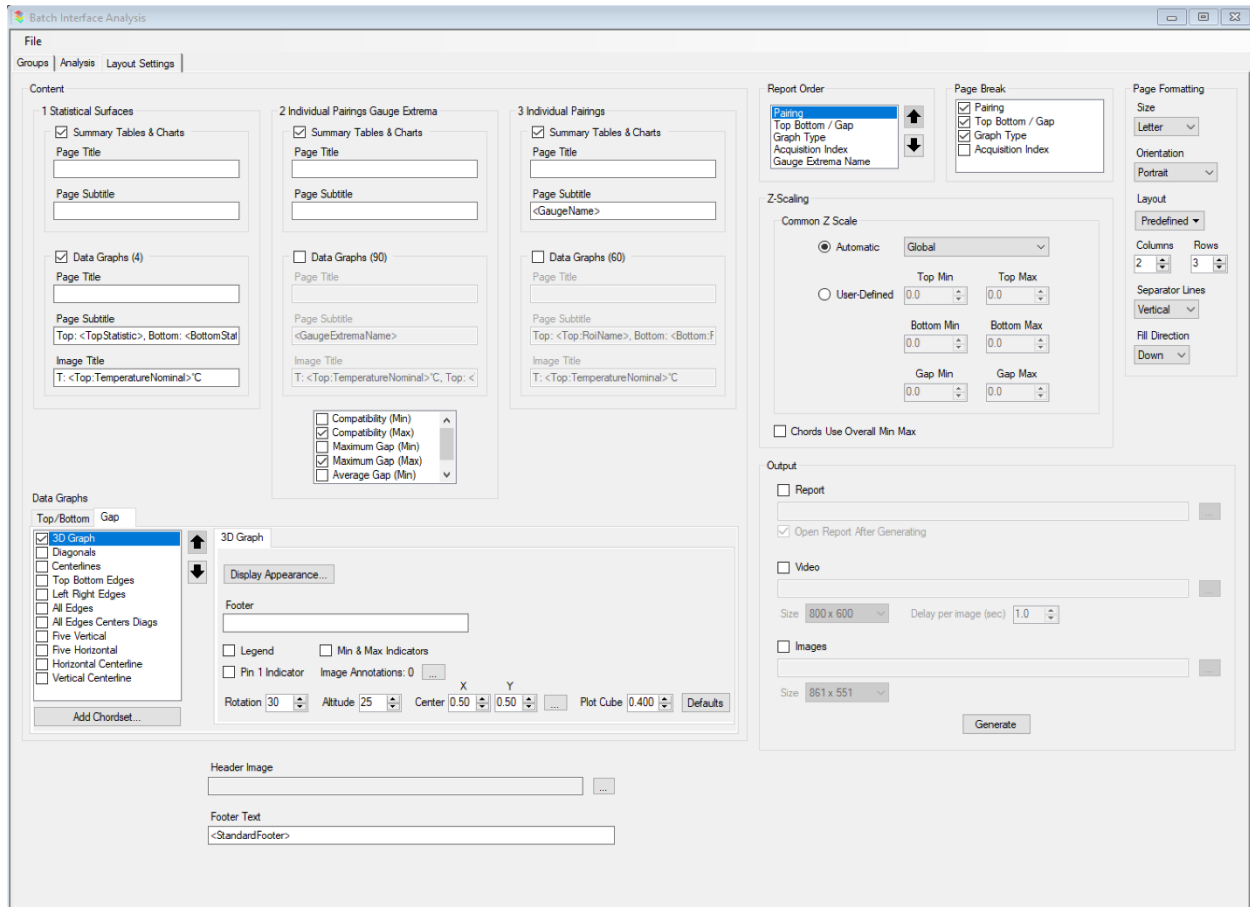


Figure 9.4 Batch IA Layout Settings Tab

To the right of these settings are the **Report Order**, **Page Break**, **Page Formatting**, and **Z-Scaling** options. **Report Order** settings determine which variables or traits are prioritized first when the report is generated while **Page Break** settings control how and when plot groups are placed on new pages. Outputs can be generated in either PDF, video, or image format. To create the selected outputs, click the Generate button.

9.4 Statistical Surfaces Output

One of the output options in Batch Interface Analysis examines the possible gaps using mathematical representations of real surfaces called Statistical Surfaces. All the Top input surfaces are rotated to a least squares fit low 0 reference plane and all the Bottom surfaces are rotated to a LSF high 0 plane. For additional information on fit planes, refer to **Akrometrix Optical Techniques and Analyses 101**. 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.

9.4.1 Statistical Surface 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.

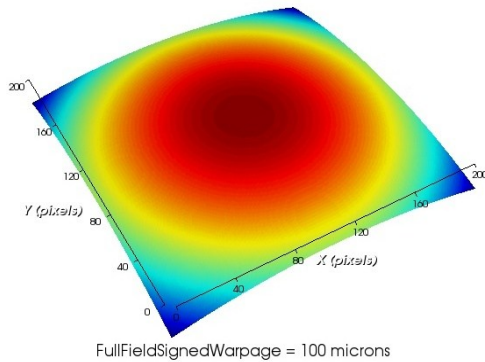


Figure 9.5 Convex LSF Low 0 Top

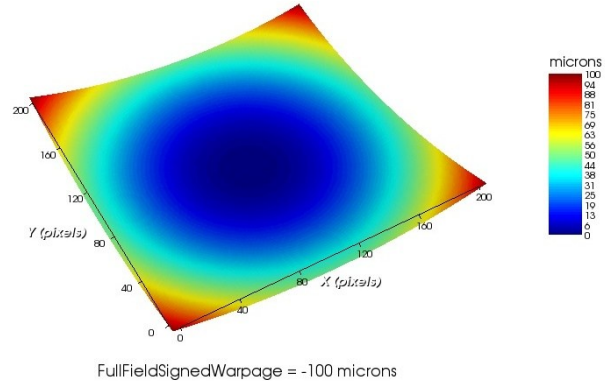


Figure 9.6 Concave LSF Low 0 Top

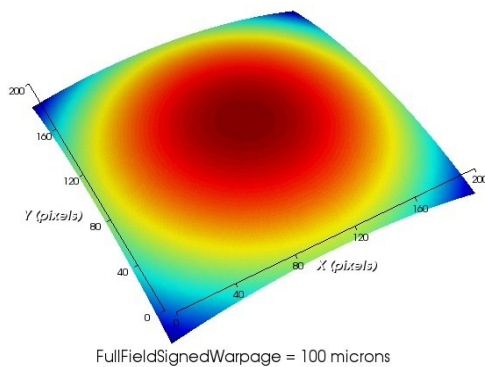


Figure 9.7 Convex LSF High 0 Bottom

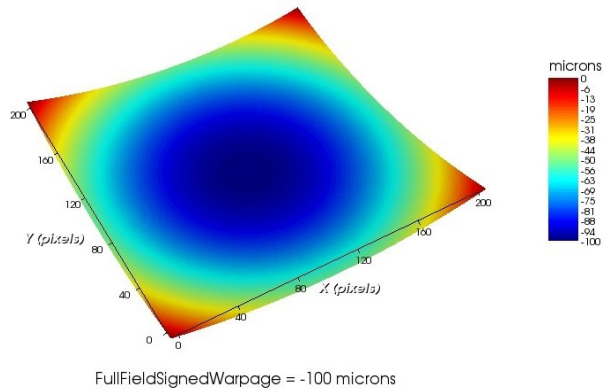


Figure 9.8 Concave LSF High 0 Bottom

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.

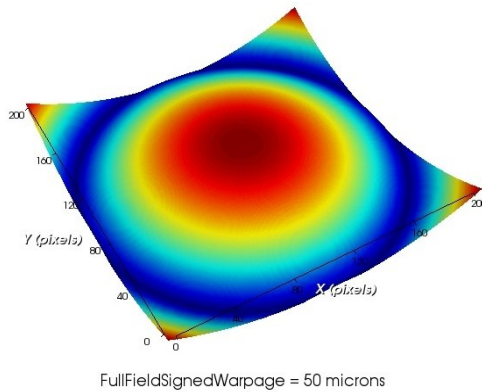


Figure 9.9 Top Maximum

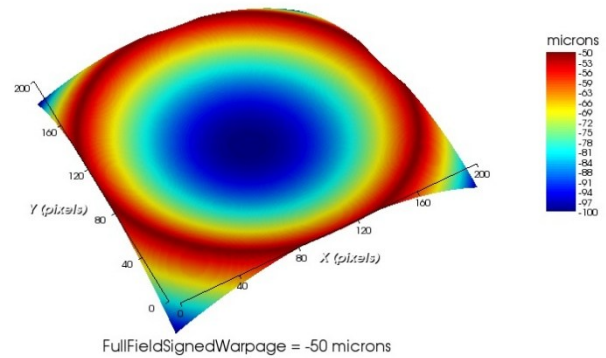


Figure 9.10 Bottom Maximum

Similarly, the following Minimum surfaces are produced:

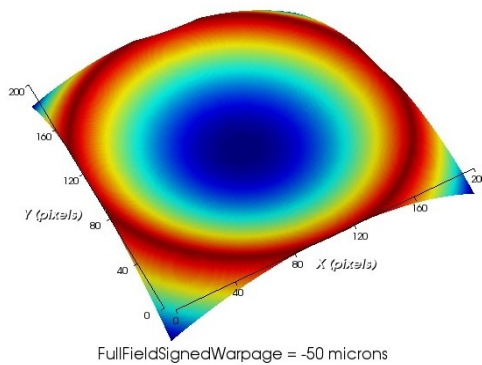


Figure 9.11 Top Minimum

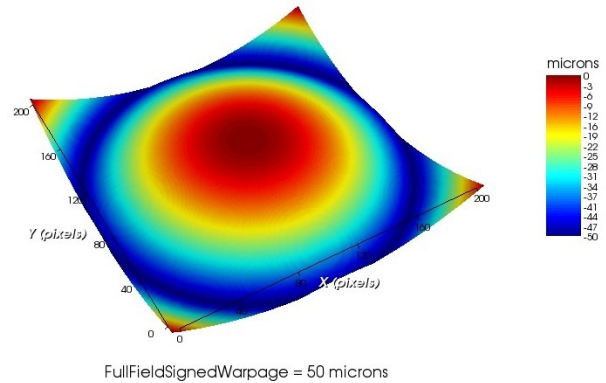


Figure 9.12 Bottom Minimum

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

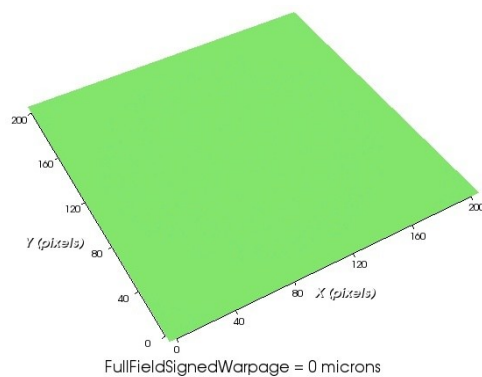


Figure 9.13 Top Average

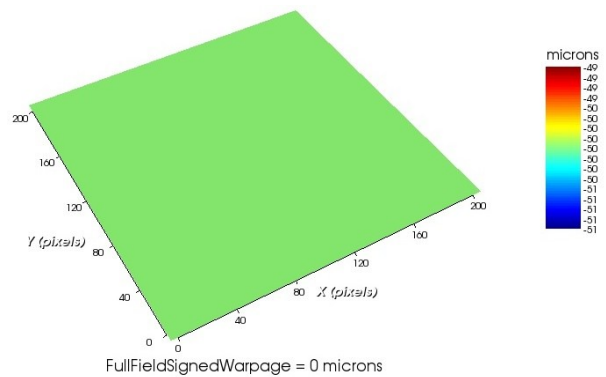


Figure 9.14 Bottom Average

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.

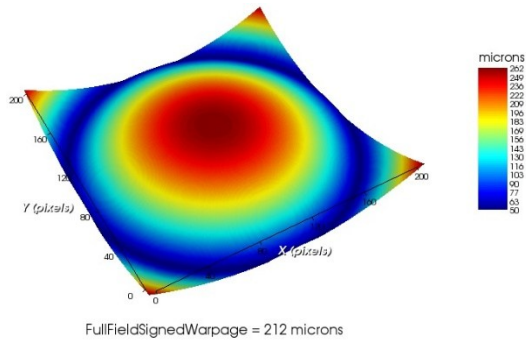


Figure 9.15 Top Three Sigma

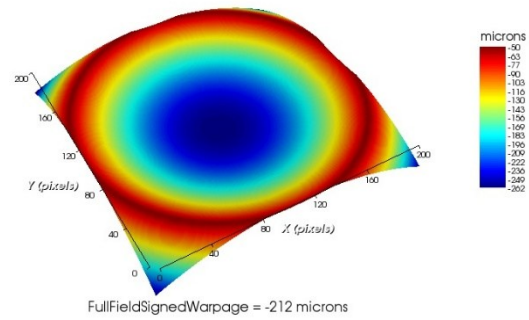


Figure 9.16 Bottom Three Sigma

10 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 10.1**) 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.

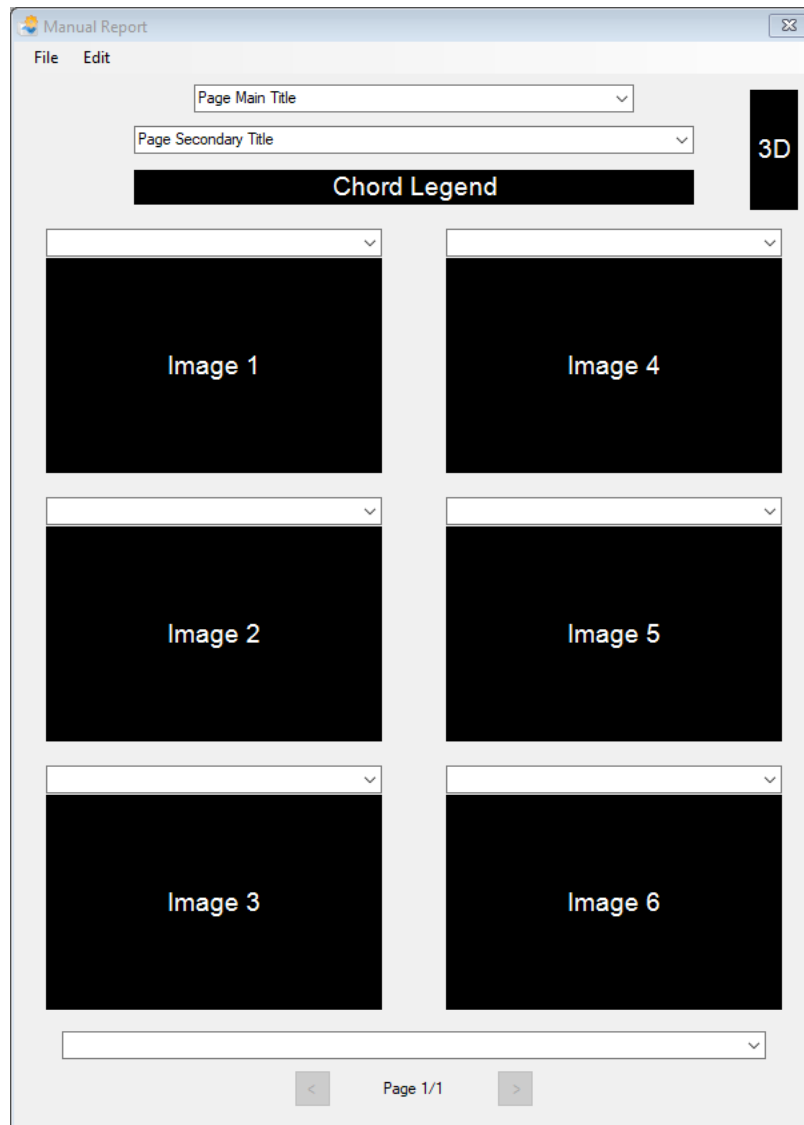


Figure 10.1 Manual Report Window

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.

10.1 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.

10.2 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.

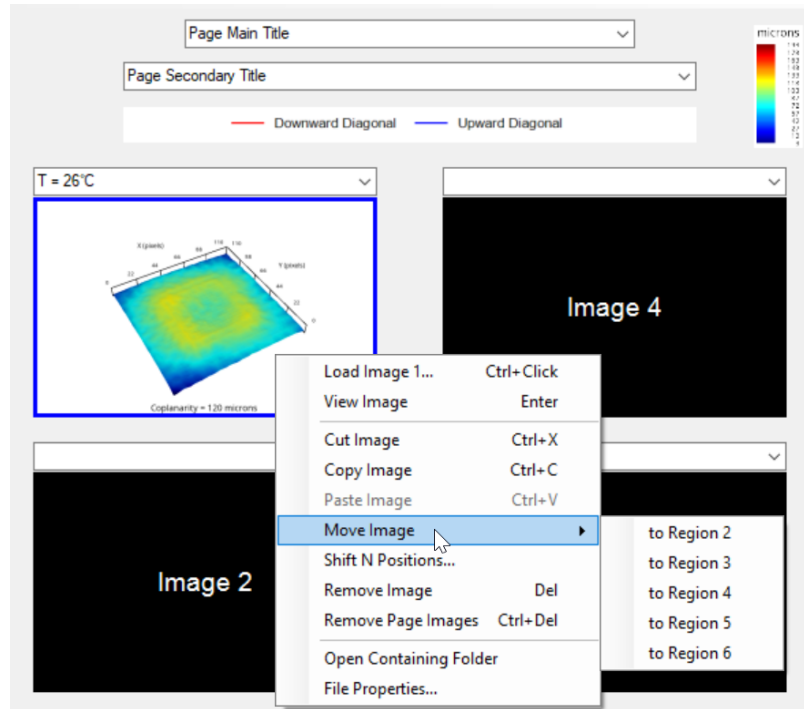


Figure 10.2 Manual Report Image Context Menu

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 10.2**).

10.3 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.

11 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.

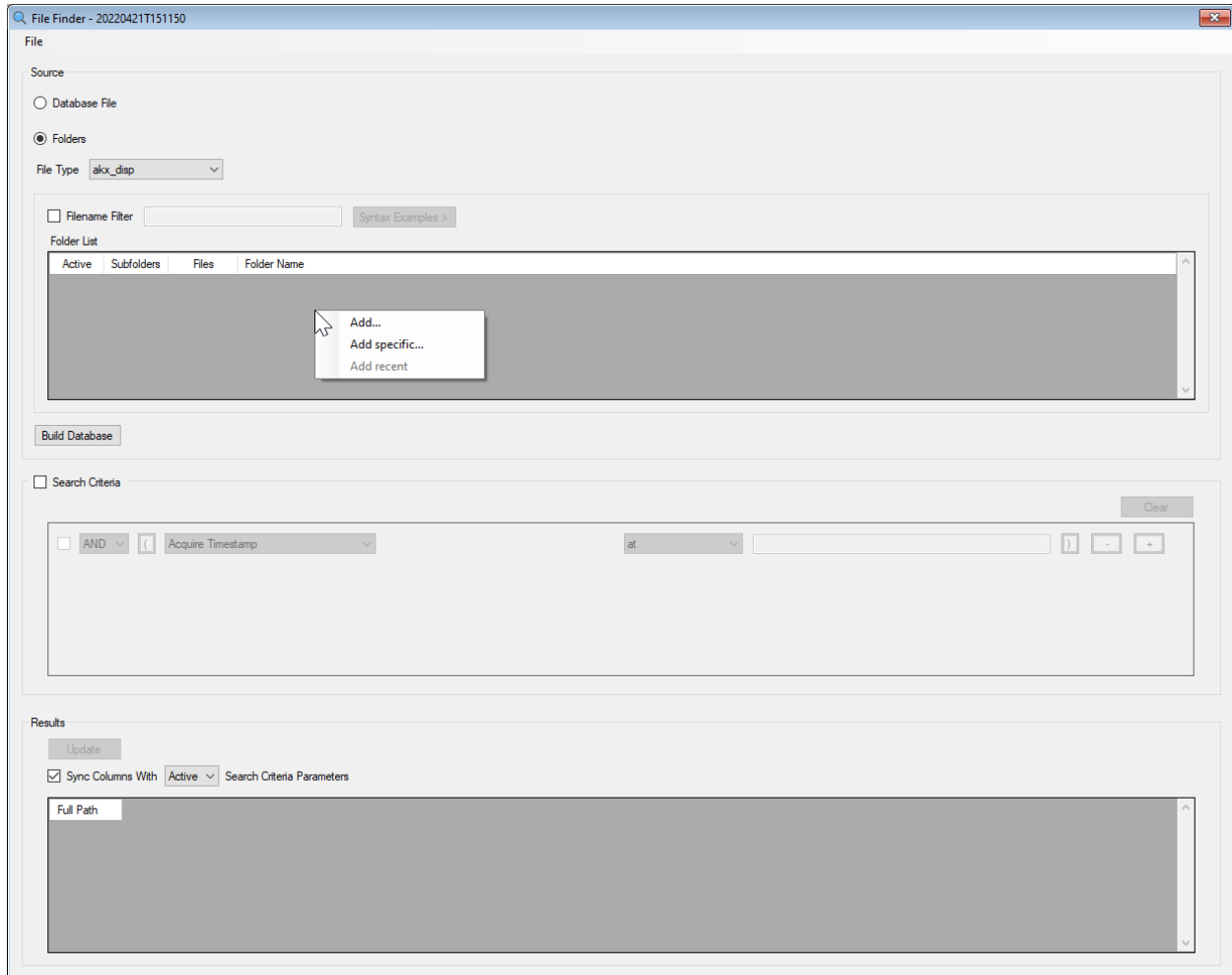


Figure 11.1 File Finder window

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 11.1**). This interface works the same way as in Batch Processing (**Section 7.1.1**). 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 11.2**) again for future queries, instead of having to re-

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

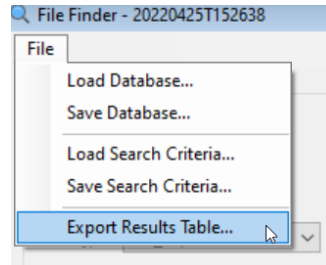


Figure 11.2 File Finder File Menu

Next, Search Criteria can be specified (**Figure 11.3**) 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 11.2**).

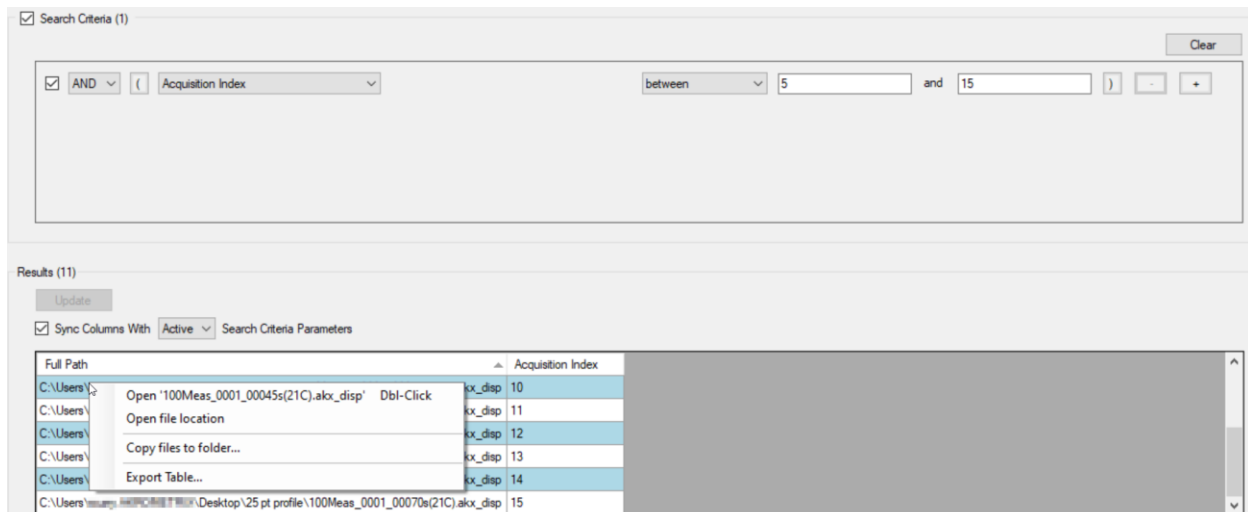


Figure 11.3 File Finder Search Criteria and Results

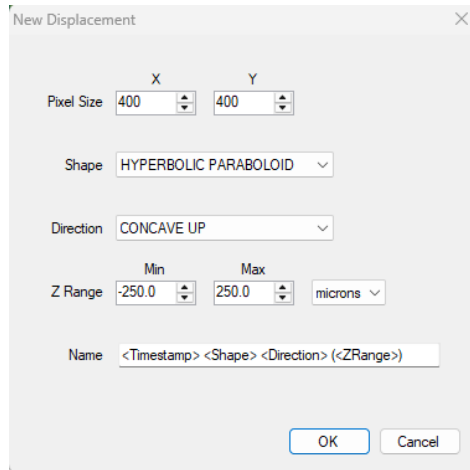
The resultant list of files can be opened via the file list context menu (**Figure 11.3**), copied to another folder, or saved as a *.csv file.

12 Part Tracking

Please see the Surface Measurement User Manual for discussion of this feature.

13 Creating Artificial Displacements

Artificial displacement files can be created using the **File→New Displacement...** function. This opens a dialog where the displacement parameters can be modified. Several different shape options are available and a new displacement file will be created when hitting OK.

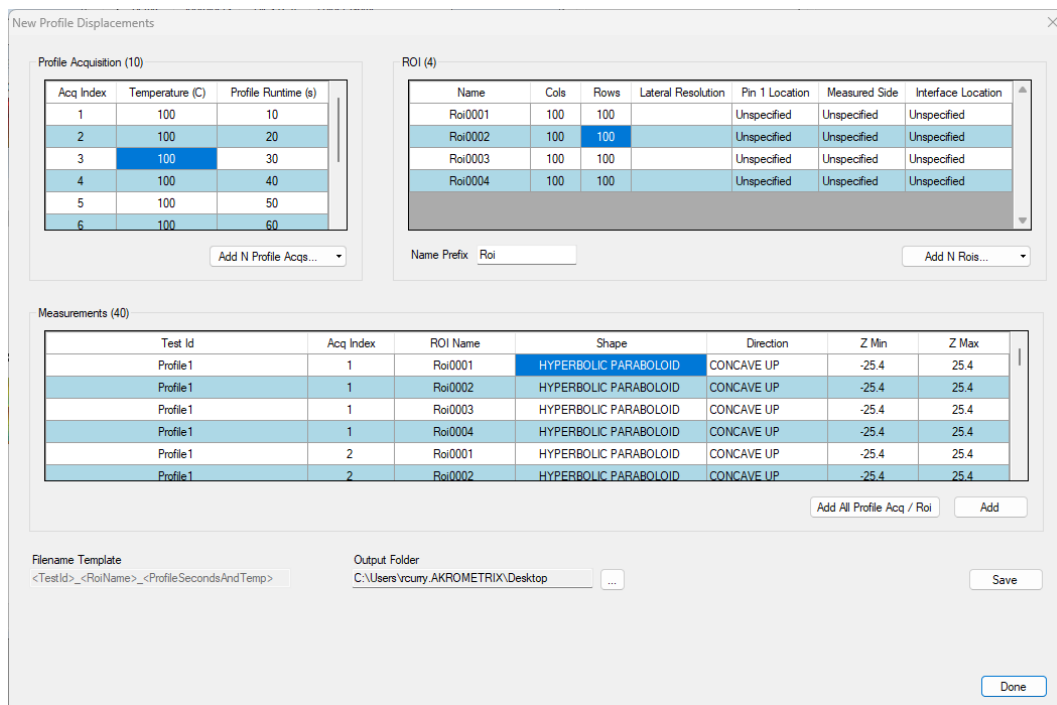


The 'New Displacement' dialog box contains the following fields and controls:

- Pixel Size:** X: 400, Y: 400 (spinners)
- Shape:** HYPERBOLIC PARABOLOID (dropdown)
- Direction:** CONCAVE UP (dropdown)
- Z Range:** Min: -250.0, Max: 250.0 (spinners), Unit: microns (dropdown)
- Name:** <Timestamp> <Shape> <Direction> (<ZRange>) (text field)
- Buttons:** OK, Cancel

Figure 13.1 New Displacement dialog

If multiple files need to be created, including artificial profile information, another option **File→New Profile Displacements...** allows creating those files. An arbitrary number of acquisitions and ROIs can be created and many metadata parameters can be modified. Clicking the **Save** button saves all the measurements to the specified directory.



The 'New Profile Displacements' dialog box contains the following sections and controls:

- Profile Acquisition (10):** Table with columns: Acq Index, Temperature (C), Profile Runtime (s). Rows 1-6 are shown.
- ROI (4):** Table with columns: Name, Cols, Rows, Lateral Resolution, Pin 1 Location, Measured Side, Interface Location. Rows R0i0001-R0i0004 are shown.
- Measurements (40):** Table with columns: Test Id, Acq Index, ROI Name, Shape, Direction, Z Min, Z Max. Rows show profiles for Acq Index 1 and 2.
- Filename Template:** <TestId>_<RoiName>_<ProfileSecondsAndTemp> (text field)
- Output Folder:** C:\Users\vcuny\AKROMETRIX\Desktop (text field with browse button)
- Buttons:** Add N Profile Acqs..., Add N Rois..., Add All Profile Acq / Roi, Add, Save, Done

Figure 13.2 New Profile Displacements dialog

14 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.

14.1 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.

14.1.1 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 14.1**, where the error originates from a step condition on the sample surface.

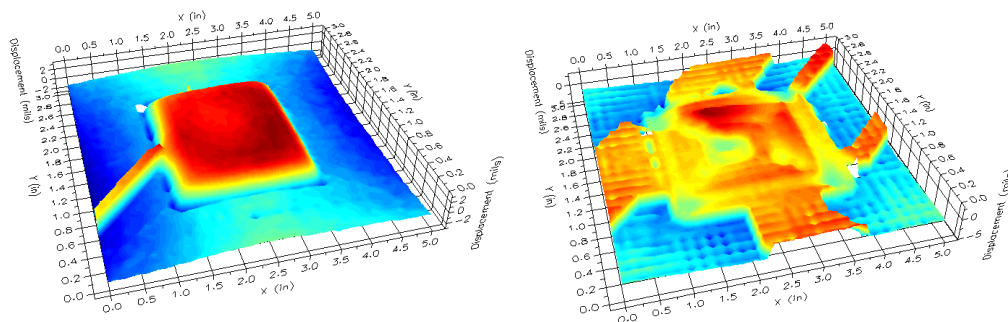


Figure 14.1 Surface Plots with Unwrapping Errors

14.1.2 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.

14.1.3 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 3.1**.



Note: Aggressive masking may create isolated data “islands” that cannot be crossed by the standard phase unwrapping algorithm. 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 (deprecated)
*.akx_2Dconfig	Configuration file for 2D plot (deprecated)
*.akx_chordset	Chord set (standard XML format)
*.akx_recipe	Stores batch processing settings for recall later.
*.akx_IASettings	Stores Interface Analysis settings

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 Profile 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
Ctrl+Shift+W	Window→Close All Windows	Closes all current windows open in Surface Analysis
F1	Help→User Manual	Open the User Manual
F9	Tools→Part Tracking...	Opens the Part Tracking window
Phase/Displacement 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.		
Ctrl+S	File→Save...	Save *.akx_phase or *.akx_disp file
Ctrl+I	File→Save Image...	Save window as image file (*.png)
Ctrl+D	File→Duplicate	Create a duplicate window of file
Ctrl+W	File→Close	Close the current file window
1-9	Display→View→Intensity 1-9	Show intensity images 1-9
QWERTY	Display→View→Intensity 10-15	Show intensity images 10-15
PageUp/PageDown or Numpad-/Numpad+		Cycle through intensity images
P	Display→View→Phase	Show Phase Image
D	Display→View→Displacement	Show Displacement Image
S	Display→View→Surface	Show Surface Image
U	Display→View→Unrotated Phase	Show unrotated phase in phase bridge mode

Ctrl++	Display→Zoom→Zoom In	Zoom in to phase/disp. image
Ctrl+-	Display→Zoom→Zoom Out	Zoom out of phase/disp. image
Ctrl+0	Display→Zoom→Zoom to 100%	Set zoom to 100%
Ctrl+B	Analysis→Unwrapping Parameters→Add Bridge...	Add bridge
Ctrl+M	Transform→Mask→Add Region	Create a new mask
Ctrl+Shift+M	Transform→Mask→Load...	Load a mask
Ctrl+R	Analysis→Partition→Add Region...	Create a new partition
Ctrl+Shift+R	Analysis→Partition→Load...	Load a partition
Ctrl+B	Analysis→Unwrapping Parameters→Add Bridge	Create a new phase bridge
Ctrl+K	Analysis→Chord→Add Chord	Create a new chord
Ctrl+Shift+K	Analysis→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 Graph Tab 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+D	File→Duplicate	Creates a duplicated window of the current data
Ctrl+P	File→Print...	Prints the image
Ctrl+C	Display→Copy View	Copies the current display window viewing angle, magnification, and plot cube to the Clipboard.
Ctrl+V	Display→Paste View	Applies the viewing angle, magnification, and plot cube saved to the Clipboard to the current display window (after Copy View is used).
Esc	Display→Reset View	Resets the Altitude, Rotation and Plot Cube back to defaults
Ctrl++		Zoom in +10%
Ctrl+-		Zoom out -10%
Ctrl+0		Reset zoom to 100%
Ctrl+Arrow		Pan the 3D data in the equivalent direction
Middle click		Pan the phase, displacement, or 3D plot
Alt+Arrow		Rotate the 3D data in the equivalent direction
Esc		Reset the Altitude, Rotation, and Center of 3D Plot
Interface Analysis Window Shortcuts		
Ctrl+T		Save top surface data
Ctrl+B		Save bottom surface data
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
Double click		Relative calculation