QviCorfac User's Guide

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QviCorfac is a utility for XY calibration of large-travel QVI measuring machines. Large-travel machines require a special calibration process because the size of the XY stage is significantly larger than the calibration artifact.

This document outlines the multi-position nonlinear calibration process using a 25-point grid artifact.

Prerequisites

Before you embark on a multi-position calibration mission, please make sure you have a good understanding of the following concepts:

- Single-position calibration (standard process on most OGP / QVI machines)
- Basic understanding of component-wise nonlinear error plots (see the QviCorview User's Guide)

Table of Contents

1. The Process

For an overview of the multi-position calibration procedure, see the Large Travel XY Stage calibration manual, P/N 790431.

2. The Software

2.1. Overview

The main features of QviCorfac are the following:

- Support for two distinct styles of data collection for calibration
- Relevant hardware parameters can be extracted from the machine's host PC
- Multiple grid measurements are automatically stitched into a single correction map using best-fit least-squares method
- All calibration and verification data can be conveniently stored in a single file for later retrieval, continuation and/or review.

2.2. Main window layout

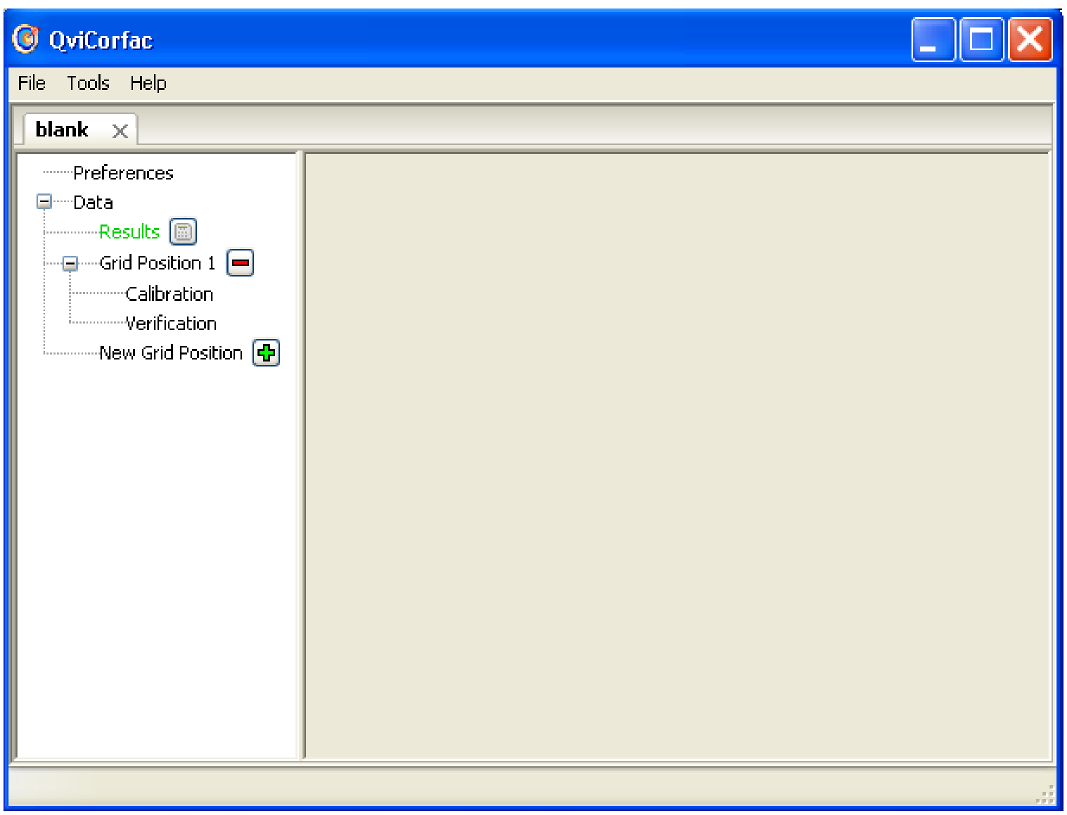


Figure 1. The main QviCorfac window

The main application window consists of a menu and a work area below it. The work area is a Notebook, whose tabs represent unique calibrations. By default, one empty calibration is created when the application is first started, with a Notebook tab named "blank". You work with a calibration by clicking on its tab in the workbook.

A calibration window under a selected tab is split into two windows, separated by a vertical sash. The sash can be dragged left and right using the mouse to accommodate the window contents, as the user deems necessary. As shown in Figure 2, the window on the left contains a tree-like representation of the calibration. As each node in the tree is selected, its contents appear in the window to the right.

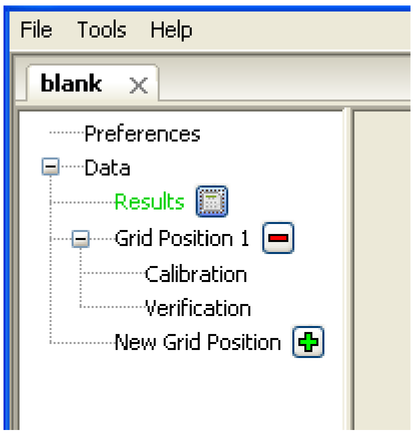


Figure 2. Session calibration tree

At a minimum, a default blank calibration contains the following items:

- Preferences
- Data
- Results
- Grid Position 1

The following paragraphs describe each of these items in detail:

2.2.1. Preferences

This section defines global calibration properties. Some of the global properties directly affect calibration results, while others do not.

Load Parameters from Host PC

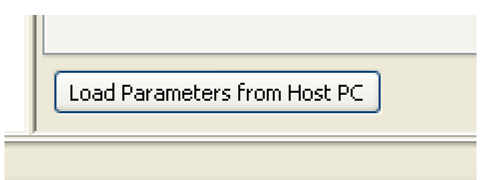


Figure 3. Load parameters button

Make sure that the correct software is selected in the General tab, then click the button "Load Parameters from Host PC" to automatically load the relevant data from the machine's PC to the Preferences. This is a convenience feature for the calibrator. Instead of manually entering values like scale resolutions, scale configurations, machine serial number, etc., this feature provides a quick and reliable shortcut. Note that the host machine's software is not automatically detected (e.g., there may be multiple metrology software packages installed, and it is up to the calibrator to select the correct one).

The Preferences window is subdivided into three main categories, listed under tabs with the following names:

2.2.1.1.General – this tab contains general information about the machine.

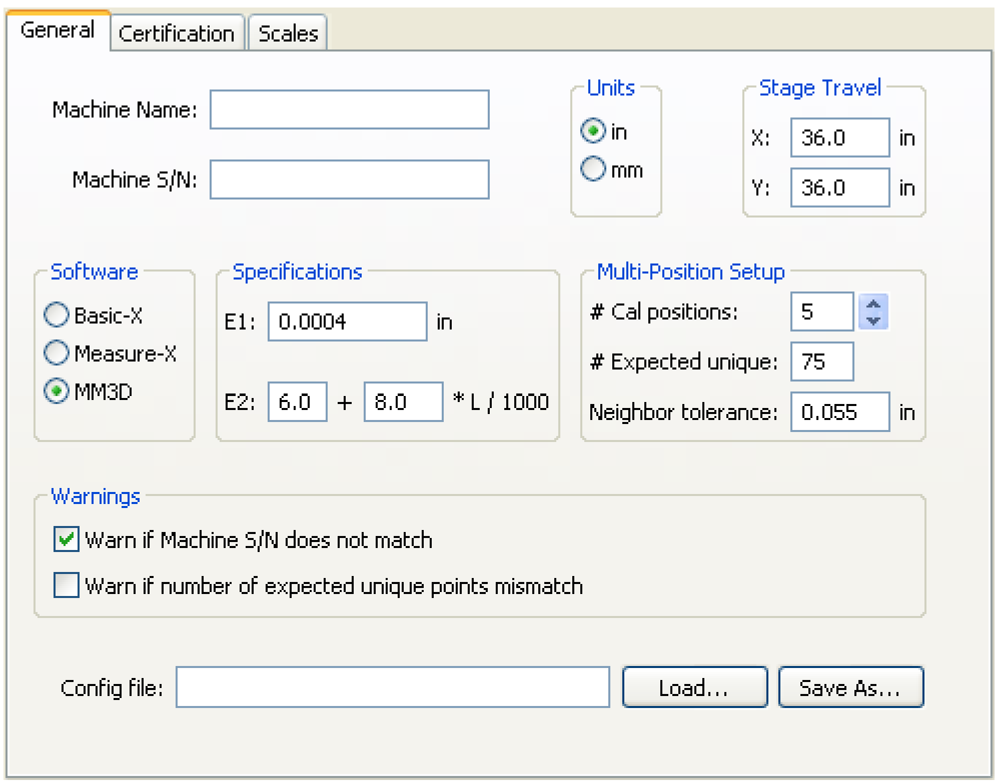


Figure 4. Preferences - general tab

Use this tab to enter general information about the calibration:

- Machine Name – the machine model name, such as CNC 900
- Machine S/N* - the machine's serial number
- Units – either inches or millimeters
- Stage Travel* – the overall X and Y travel of the stage
- Software – the software that will use the results of this calibration
- Specifications* – the E1 and E2 tolerances for evaluating XY stage performance with corrections applied.
- Multi-Position Setup:

- Number of grid positions during calibration – this depends on the relative size of the XY stage and the grid artifact. Generally, the larger the stage, the more grid positions will be necessary to perform calibration.
- Number of expected unique points in the overall pattern – after calibration data is collected, the number of points in the grid pattern will be less than the total number of sampled points because of overlap; set the expected number here.
- Neighbor tolerance – during overlap calculations, a square box is applied around each sampled point to determine which other points overlap with it. The square's side dimension is twice this tolerance.

- Warning options:
  - Warn if the machine serial number does not match the serial number in the verification reports
  - Warn if number of expected unique points does not match the number of unique points found by the software after stitching the collected data
- Config file – load or save a file that contains all the options in Preferences.

* The "Load Parameters" button can automatically populate these items.

2.2.1.2. Certification – define the grid data file and the certification scheme.

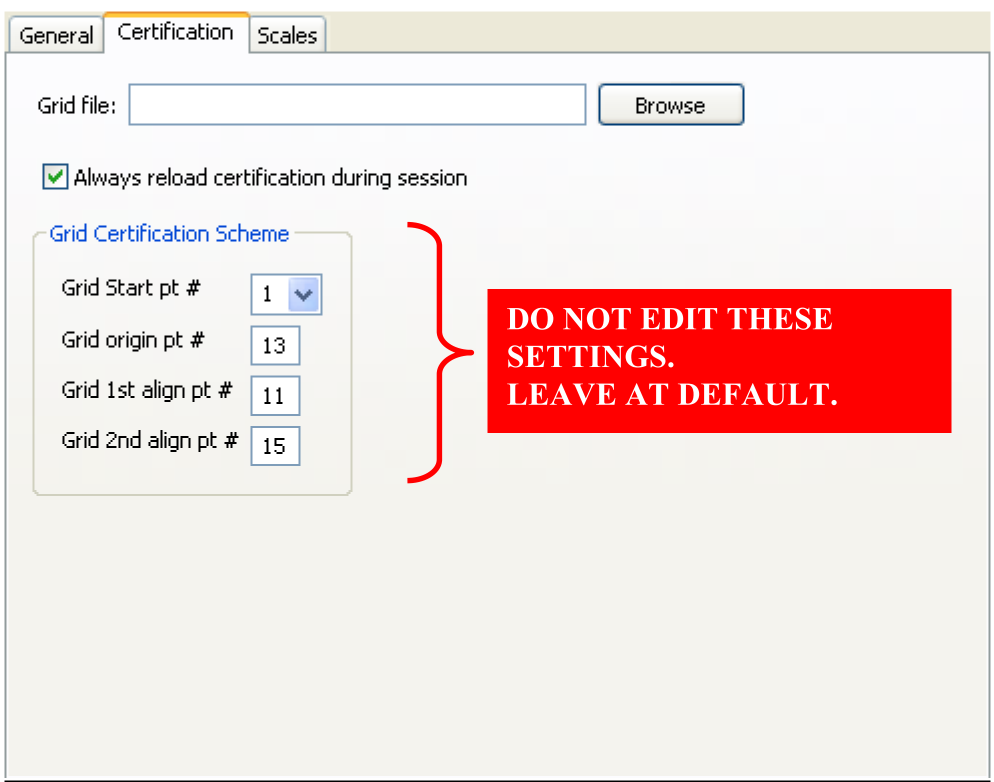


Figure 5. Preferences - Certification tab

The grid data file usually comes with the certified grid artifact on a floppy disk. The certification scheme simply defines the grid layout. It is described by:

- The start point number (either zero or one)
- The grid origin point number (13 by default)
- The grid's first alignment point (11 by default)
- The grid's second alignment point (15 by default)

Note: PTB dot plates use a "1-1-5" alignment scheme. That is, the grid origin is #1, the first alignment point is also #1, and the second alignment point is #5.

The certification scheme information is only relevant when the measure style is set to "Verifications with offsets" (see 2.2.2 below).

2.2.1.3.Scales –define the hardware scale configuration.

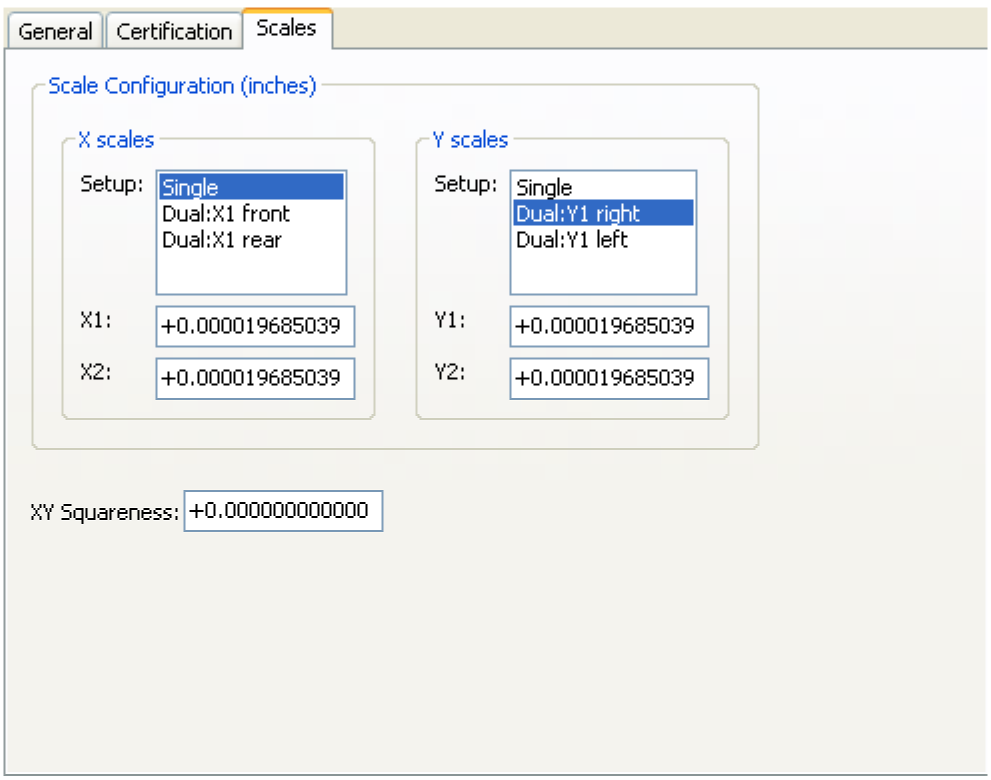


Figure 6. Preferences - Scales tab

The X and Y scales are of primary concern here. Each axis can have either single or dual scales. If there are dual scales, then the arrangement of the primary and secondary scales must be defined as well. Do this by selecting the appropriate choice in the "Setup" list. Set the appropriate scale resolutions here as well. By default, 0.5-micron scales are used. This tab also defines the XY Squareness factor value.

Note: All of the settings on this tab can be automatically populated by the "Load Parameters from Host PC" button.

2.2.2. Data

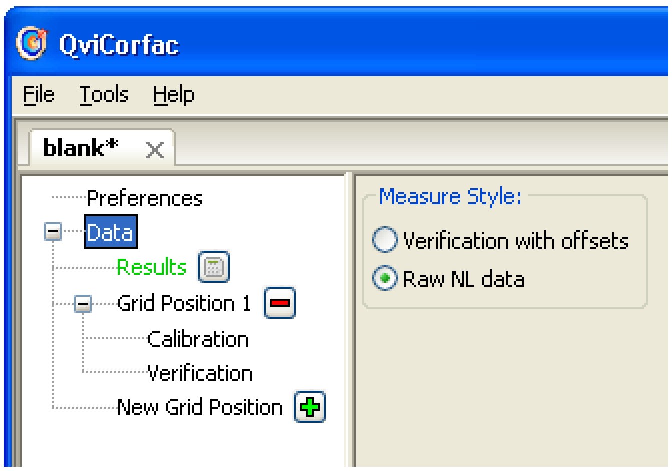


Figure 7. Calibration tree - Data item

This window defines the measure style. Two choices are available:

- Verifications with offsets
- Raw nonlinear data

The "Verifications with offsets" style is the legacy measurement style that was used when this calibration process was first developed. It is more time-consuming than the "Raw nonlinear" style because the grid's coordinates have to be measured and recorded, but it does not require the machine's existing nonlinear correction setup to be disturbed until the end of the data collection process. The disadvantage is that the grid is measured only in the forward direction. The advantage is that the grid can be measured multiple times to obtain an explicit measure of repeatability while collecting calibration data.

The "Raw nonlinear data" style, on the other hand, inherently provides the necessary grid offsets; but it requires that the machine be locally calibrated over each grid position. The local calibration is temporary and is typically not a problem. The primary advantage of this method is that the grid is measured in the forward and the reverse direction, thus minimizing hysteresis effects. The disadvantage is that the calibration report does not provide repeatability data. This necessitates a number of verification runs (typically three) before the calibration to establish the machine's repeatability. This is highly recommended because good repeatability establishes a comfortable confidence level in the overall calibration.

The difference in calibration results between the two methods is negligible. The raw nonlinear measurement approach is the default and is highly recommended because it is faster and less prone to operator error.

2.2.3. Results

This window contains all results of the calibration. The results section is empty until calibration data is collected and the results are calculated. The color of this tree item shows the state of the results. If it is green, the results are "clean": they are either empty or have been calculated, and no changes have been made to the inputs. If it is red, it means that some input data has changed, and the results must be recalculated. The results are broken down into the following categories:

2.2.3.1. Linear results

Here is a sample display of linear results:

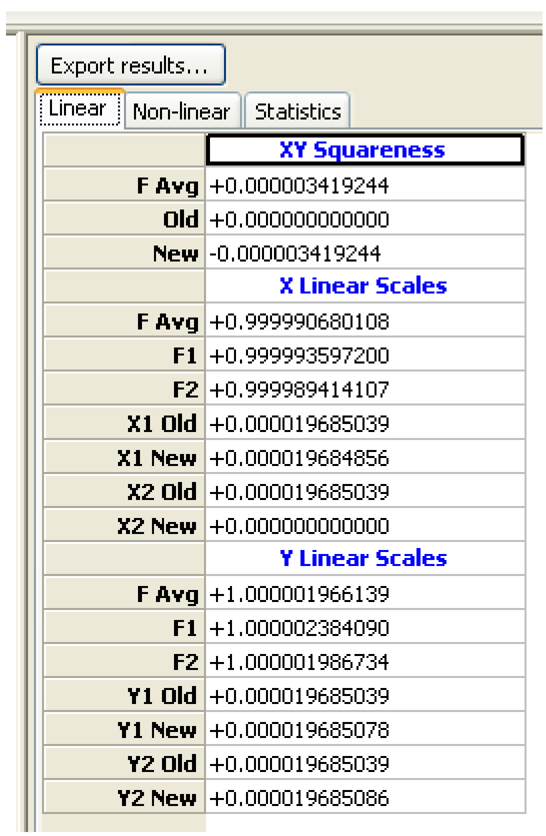


Figure 8. Linear results (sample)

All results pertaining to linear factors are stored here. This includes the following information:

- *XY Squareness* – F Avg, Old, New
- *X Linear Scales* – F Avg, F1, F2, X1 Old, X1 New, X2 Old, X2 New
- *Y Linear Scales* – F Avg, F1, F2, Y1 Old, Y1 New, Y2 Old, Y2 New

Several of these values have similar meaning. They can be described as follows:
F Avg is the average calculated value based on the entire set of data.
F1 (where applicable) is the average linear factor based on two grid columns nearest the stage home position.
F2 (where applicable) is the average linear factor based on two grid columns farthest away from the stage home position.
Old is the existing value of the particular linear factor.
New is the new value of the particular linear factor, as calculated based on the input data.

2.2.3.2. Nonlinear results

Here is a sample display of nonlinear results:

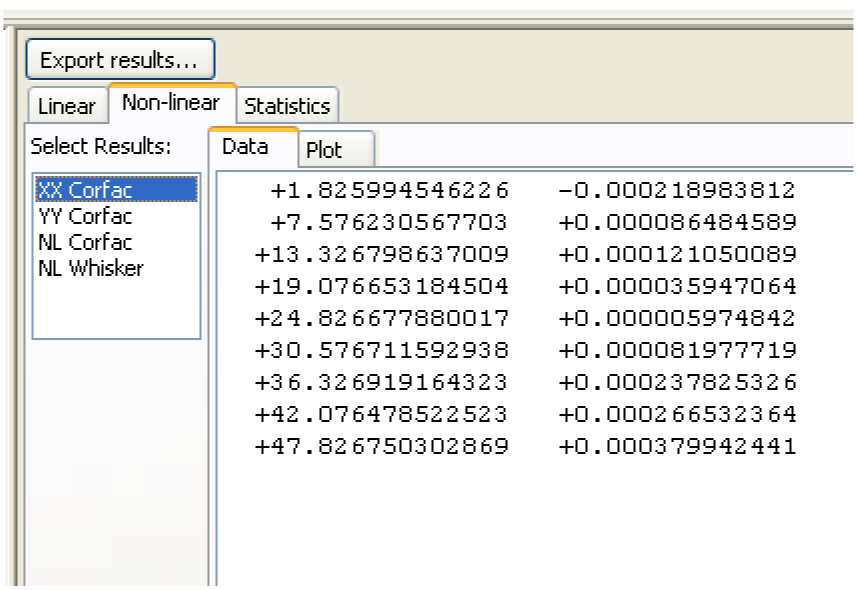


Figure 9. Nonlinear results (sample)

Fundamentally, this window shows three nonlinear results:

- XXCORFAC
- YYCORFAC
- NLCORFAC

The window consists of two parts: a selection list on the left and a window with two tabs on the right – the Data tab and the Plot tab. There are actually four selections in the list because NLCORFAC can be displayed in two ways – as component-wise plots, and as a whisker plot. Both of those plots convey exactly the same information.

When any of the choices in the selection list is highlighted, the Data tab always displays the raw contents of its associated correction file. The Plot tab shows the associated visual view of the selected data.

2.2.3.3. Statistics

This window displays the fit statistics that were generated during the calculation procedure. It includes a number of information items that may be useful during troubleshooting.

IMPORTANT NOTE ABOUT THE APPLICATION OF RESULTS:
Please note that the linear results and the nonlinear results represent equivalent calibration states of the machine, but in an exclusive manner. That is, both sets of results cannot be applied at the same time if AND ONLY IF the results were obtained from the same set of input data. By the same token, if you choose to apply only the nonlinear results, then NLCORFAC must be applied exclusive of XX/YY CORFAC.

This stipulation is due to the fact that the metrology software applies stage corrections in the following order:

- Linear corrections
- Single-axis nonlinear corrections (XXCORFAC, YYCORFAC)
- Two-dimensional nonlinear corrections (NLCORFAC)

This order means that any correction affects all of the corrections that are applied downstream. It is possible to calibrate a machine using any number of the above three corrections, provided that proper protocol is followed during calibration. The basic idea is that the corrections at any given level must be calculated after upstream corrections have been established and are deemed acceptable, AND with all of the downstream corrections disabled. Once the corrections at the given level have been calculated and enabled, then one can move on to calculate any downstream corrections if necessary.

2.2.4. Grid Position "X"

If the measure style is set to "Verifications with offsets", then this window is used to input the grid offset coordinates; otherwise, there is nothing for the user to do here.

A grid position may be removed from a calibration by clicking the button to the right of this tree item.

2.2.4.1.Calibration

This window contains the calibration input data for the particular grid position.

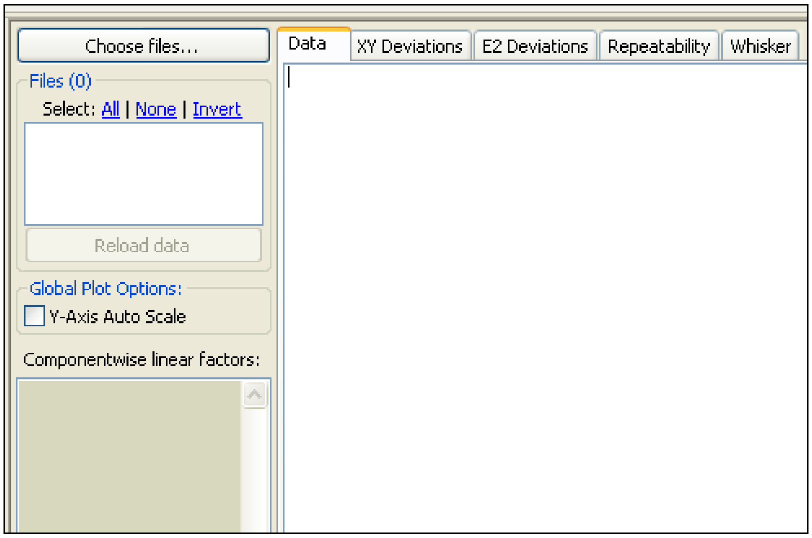


Figure 10. Calibration window without data

To add files to this grid position's calibration set, click the "Choose files…" button. A dialog will pop up that will allow you to browse to the file(s) you want to add. Note that you can select multiple files in the dialog by holding down the Ctrl key on the keyboard. The file type that the dialog will allow you to select will vary depending on the measure style of the calibration:

- Verification with offsets – the Calibration file picker will default to verification files (*.txt).
- Raw NL data – the Calibration file picker will default to NLCORFAC files (*nlcorfac*.cfg).

Note that the above defaults are provided merely for convenience. You can load a file with any name and extension as long as you know that the file format is appropriate to the calibration style. In such cases, select the "All files(*.*)" type in the browse dialog and choose your file(s).

Also note that the current set of calibration data for the grid position is entirely replaced by the selection you make. The old data set is discarded, and this operation cannot be reversed.

After you make a selection, the data will be loaded into the session and you will be able to view it in detail:

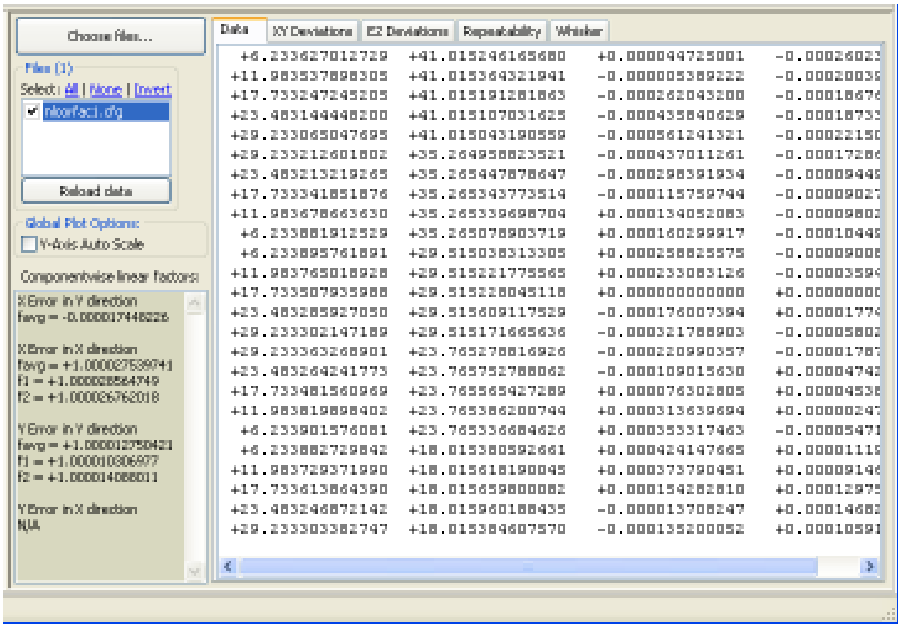


Figure 11. Calibration window with loaded data

The left pane of the window contains three major controls:

- File picker – the file that is highlighted in the list is displayed for review in this window. The file(s) that are checked in the list are used during calibration calculations. Files that are not selected in the list are ignored during calculations.
- Global plot options – this simply contains a check box that auto-scales the y-axes of the data plots to fit the window.
- Component wise linear factors – this text window lists the calculated component errors of the stage over the area of this grid position. You can copy text from this window by highlighting it and clicking the right mouse button.

The right pane of the window contains five tabs:

- **Data** – displays the raw text view of the highlighted data file.
- **XY Deviations** – displays the component wise plots. If multiple files are checked on, their deviations are averaged.
- **E2 Deviations*** – displays the E2 tunnel plot. If multiple files are checked on, all the data is displayed as-is, without any averaging.
- **Repeatability*** – displays the overall repeatability of the selected data.
- **Whisker** – displays a whisker plot of the selected data. If multiple files are checked on, their deviations are averaged.

* E2 deviations and Repeatability plots are not displayed for NLCORFAC files.

2.2.4.2. Verification

This window contains the verification data that is collected after placing the calibration into effect on the machine.

This window has exactly the same look and feel as the Calibration window. There are only a few differences in functionality:

- The verification data is for reference only. It is never used in any calculations that affect the results of the calibration.
- When using the file picker dialog, the file type always defaults to verification files regardless of the measure style.

2.2.5. New Grid Position

Additional grid positions can be added as necessary by clicking the ✚ button to the right of this tree item. No other action is possible here.

2.3. Preference templates

A calibration's Preferences can be saved to a template file, which can be loaded later. Select the Preferences tree item, then look for the text box labeled "Preferences file:" on the General tab. Click the "Load…" button to load an existing template, or click "Save As…" to save the current preferences to a template.

QviCorfac is distributed with a number of Preference files for common machines, such as the Flash/CNC 900, the Flash 1500, Flash 1550, and Flash 1552. These files can be found in the `samples\templates` directory within the application directory. All of these templates assume that the calibrator will use a 24"x24" grid for the calibration. If your calibration grid is of a different size, please refer to Appendix A for information about determining the number of grid positions as well as the number of expected unique points.

2.4. Starting a new calibration

A blank calibration is created automatically when the application is started. You can also create a blank calibration at any time by pointing to the File>New menu.

2.5. Retrieving a previously saved calibration

Go to File>Open menu, browse to a previously saved calibration file, select it and click Open. The calibration will open in a new Notebook tab.

3. Appendix A – How to determine the number of grid positions and unique points

3.1. Introduction

Although QviCorfac is distributed with a number of preference templates, they all assume that the grid artifact is of a specific size. Therefore, the number of calibration positions and the number of expected unique points in the preference templates are based on this assumption. In the field, one may encounter situations that stipulate the use of a grid of a different size, or it may be advantageous to use a different number of grid positions for a particular calibration. In any case, it is helpful to understand how to determine the number of grid positions and unique points based on a given machine stage and grid artifact.

3.2. What are these "unique" points?

First, let us consider a very simple hypothetical example before studying a real case. Let's say that we want to calibrate an imaginary 48"x24" stage using a 24"x24" grid. The stage travel is typically a few millimeters more than the nominal 48"x24", and the dimensions of the 24"x24" grid are 23"x23". Hence, the XY spacing of the grid intersections is nominally 5.75". We can easily see by observation that the Y travel of the stage can only accommodate five grid rows i.e., one grid position. What is the minimum number of grid positions that the X travel will allow? To determine that, first divide the available X travel by the grid's X spacing: 48" / 5.75" = 8.348… Do not round the result up or down. Simply drop the remainder and add 1. This means that we can fit 9 columns of the grid within the stage's X travel.

The calibration works best when there is a grid intersection in the middle of stage travel. A standard OGP grid artifact has an odd number of rows and an odd number of columns. In order to have an intersection in the middle of the stage, any combination of grid positions must end up with an odd number of rows and columns. Therefore, if you go through the procedure in the previous paragraph and find that your combination allows for an even number of rows or columns, you must reduce those number(s) by 1 to keep them odd. For example, it is not possible to have a combined pattern that is 5 rows and 8 columns. Such a pattern does not have a column at its center. Therefore, we must position the grid in such a way as to arrive at 7 columns in the pattern.

Once you determine how many rows and columns you will use, draw a simple picture of the grid intersections to visualize the grid positions. It is imperative that the first grid position is located in the center of stage travel. All other grid positions should be offset from it. Once you visualize the overall pattern, tally the number of <u>unique</u> points. The unique points in the pattern are one of the following:

- A single intersection in the pattern
- Any number of intersections in the pattern that overlap with each other

3.3. How to determine the number of grid positions in general

We must first determine the maximum number of grid rows and columns that will cover the calibration area of the stage. As was partially illustrated by the imaginary example above in 3.2, the general approach to determining the number of rows and columns in the overall pattern is as follows:

- Determine the X and Y dimensions of the grid.
- Determine the X and Y spacing of the grid by dividing the appropriate dimension by ($n - 1$), where n is the number of intersections along that dimension.
- Divide the stage travel of each axis by the appropriate grid spacing, as determined by the orientation of the grid on the stage. Drop the decimal remainder from this result, and add 1. This is the <u>whole</u> number of grid intersections that will fit along this axis.
- If any count of rows or columns is an even number, reduce that count by 1 so that the counts of rows and columns are always odd. This guarantees an intersection in the middle of the calibration area.

To determine the minimum number of grid positions required to cover a given direction, use the following formula:

$$k = \frac{n-1}{p-1}$$

where:

$n =$ number of allowable intersections along the direction of interest

$p =$ number of grid intersections along the direction of interest

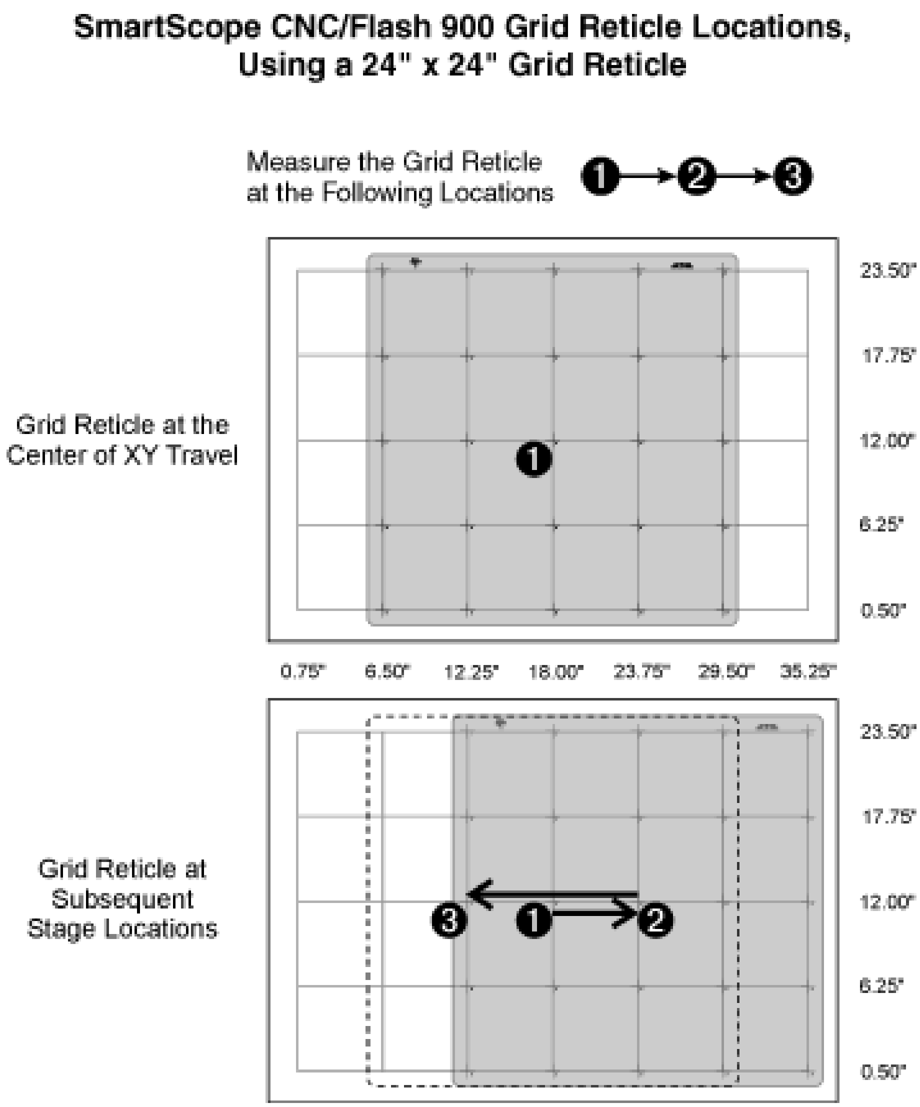
$k =$ MINIMUM number of grid positions required to cover the direction of interest

Round k up to the nearest whole integer.

It is imperative that any two positions of the grid on the stage must intersect at a minimum of two intersections for proper results. On the other hand, do not cover the calibration area with too many grid positions. This wastes the calibrator's time and more importantly, does not improve the overall accuracy of the machine.

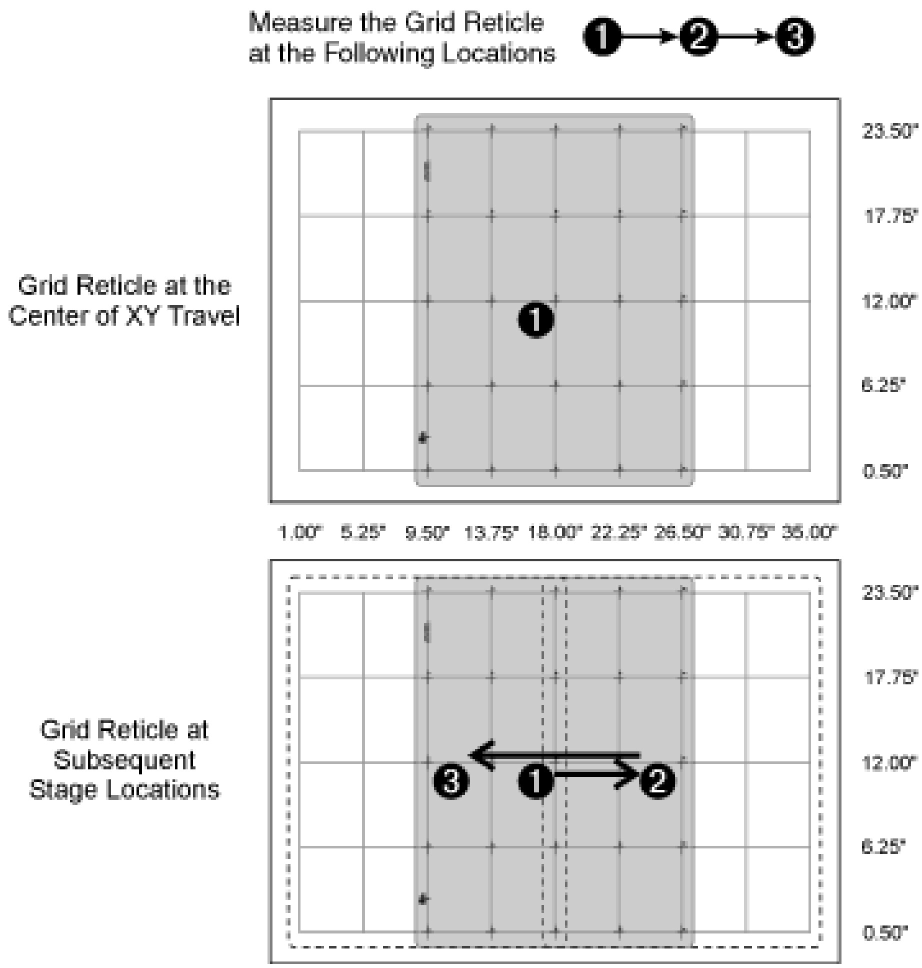
4. Appendix B - Examples of Grid Patterns

Note: Unless otherwise specified in the diagrams, the grid used in the following illustrations is a 24"x24" grid (actual dimensions: 23"x23").

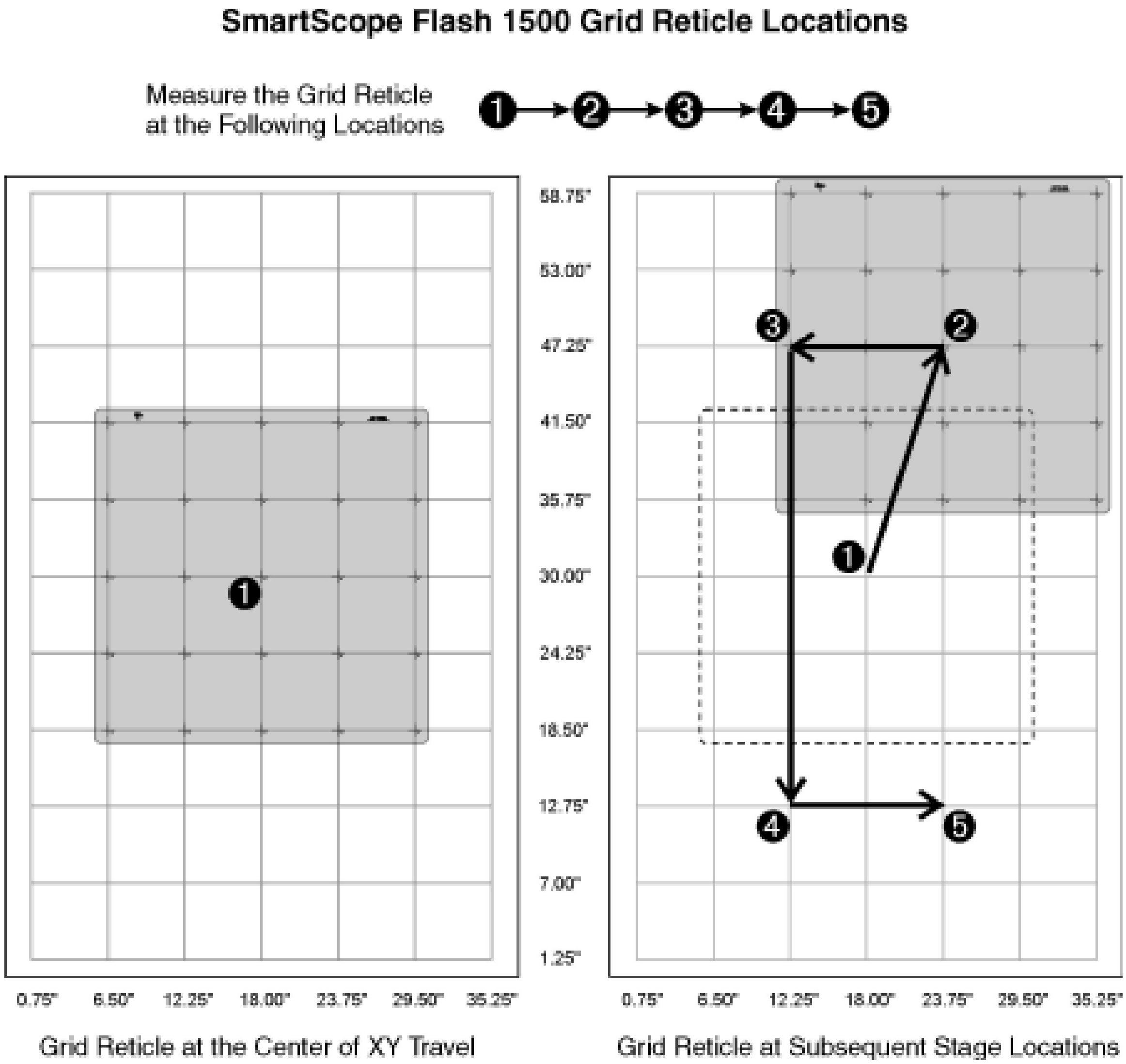


Appendix B - Examples of Grid Patterns (continued)

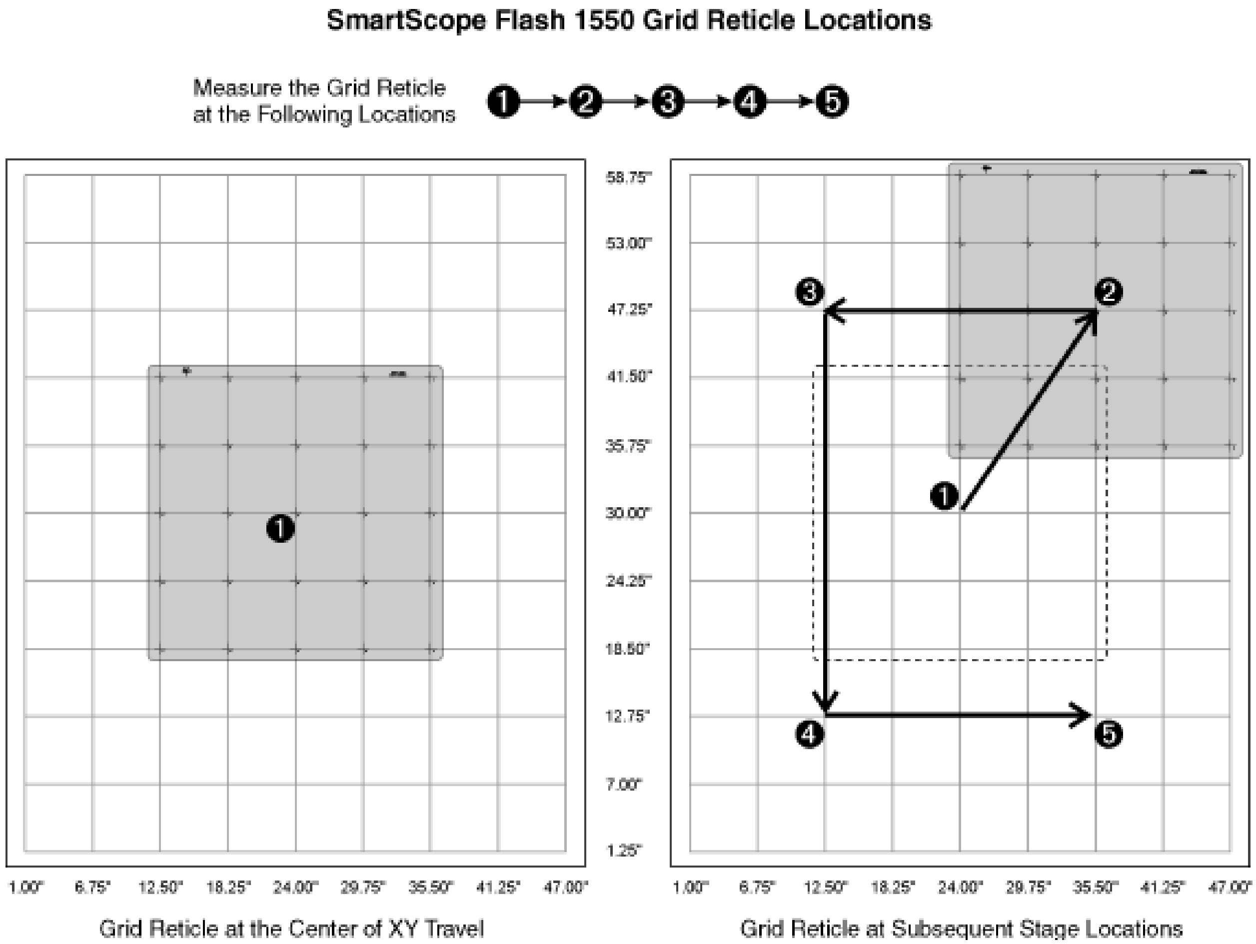
SmartScope CNC/Flash 900 Grid Reticle Locations,
Using a 18" x 24" Grid Reticle Rotated 90°



Appendix B - Examples of Grid Patterns (continued)



Appendix B - Examples of Grid Patterns (continued)



Appendix B - Examples of Grid Patterns (continued)