

# Error Map Explorer Users Guide

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# Error Map Explorer Users Guide

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## Introduction

The Error Map Explorer utility was written to allow users to view the effects of compensation map data on a coordinate measuring machine. The correction values are calculated to the position of the active probe stylus and should be comparable to methods used by most CMM inspection software.

The correction that is applied to machines from the compensation error map can be very difficult to visualize especially if more than one parameter is active at any one time. To make this easier individual errors or combinations of errors can be activated or deactivated showing the effect immediately. Without this feature it would be necessary to create a series of compensation map files containing only select parameters and load them one at a time.

Test data can be recorded and then subsequently played back for automated comparison. This feature was added for testing where many combinations of errors and probe offsets are needed to fully evaluate a compensation error map. This feature is particularly useful for testing unknown compensation methods used by third parties.

The Error Map Explorer utility can load compensation maps from a variety of manufacturers. A sample error map is provided with this utility for evaluation purposes. A sample test sequence was also created for this error map to demonstrate the capabilities.

Where suitable, the interpretation of the compensation error map matches that of the manufacturer. Some compensation maps use features such as non zero rotation points which can have advantages in certain situations. The effect of features like this can be easily seen in the correction data.

This utility is cross platform compatible and can be run on GNU/Linux, OSX, and Windows.

## Overview

The purpose of the Error Map Explorer utility is to load an existing coordinate measuring machine error compensation map and perform a simulated move through the volume. The amount of correction that is applied for any position in the machine is shown as the difference between the two sets of coordinate displays.

The left side of the main window is for the axis limits where the right side has all the options related to the active compensation error map. Three sliders are used to set the position of the simulated CMM in the machine volume. The range and step size of the sliders are defined in the limits section. The kinematic axis order and active errors is controlled from the options section of the Error Map Explorer.

Two sets of coordinate displays show the uncompensated and compensated position of the simulated CMM. Both coordinate displays can be offset by the active probe which mimics how most CMM software deal with probe offsets.

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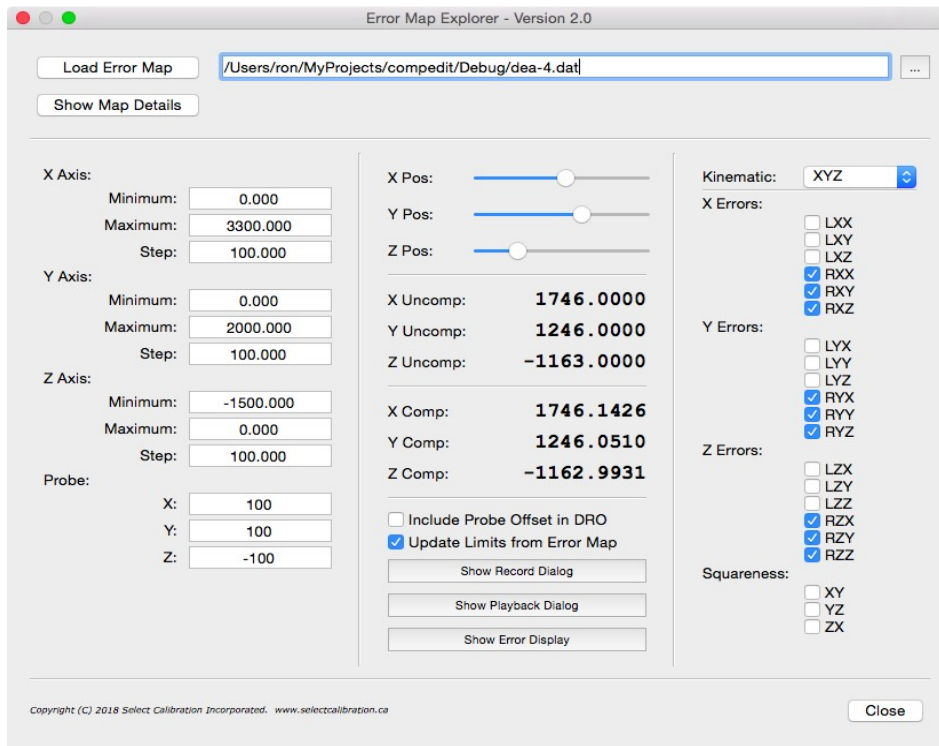
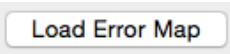
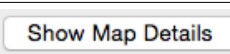
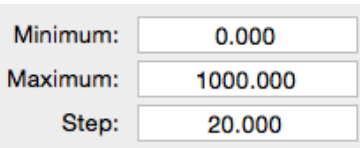


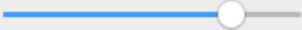
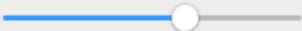
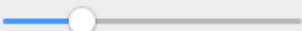
Illustration 1: Main window of the Error Map Explorer utility with an error map loaded. The limits section is on the left and the compensation options are on the right.

Some features of the Error Map Explorer utility such as the Error Display and Playback Dialogs can be shown or hidden as necessary. These windows will float independent of the main window of the Error Map Explorer utility.

## Options

Item	Description
	<p>Load the error map from the file shown on the right of this button. The browse button on the right side of the file path can be used to select a file using the standard File Open dialog.</p> <p><i>Compensation maps can be loaded by dragging and dropping the file onto the Error Map Explorer utility program as an alternate method.</i></p>
	<p>Display information about the loaded compensation file. See Compensation Map Information section below.</p>
	<p>Minimum, maximum, and step for each of the three coordinate measuring machine axis. The position of the machine is controlled from the axis position sliders and these fields are used to define the range of the three sliders.</p>

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Item	Description
	<p>The step value is set to the absolute increment value of the map axis. This value controls the step size of the axis sliders.</p>
<p>Probe:</p> <p>X: <input type="text" value="100.000"/></p> <p>Y: <input type="text" value="0.000"/></p> <p>Z: <input type="text" value="0.000"/></p>	<p>Probe offset connected to the last axis of the CMM. The compensation is calculated to the center of the probe stylus defined by this offset.</p> <p>A representation of the probe will be drawn in the error display window.</p>
<p>X Pos: </p> <p>Y Pos: </p> <p>Z Pos: </p>	<p>Sliders used to position the simulated coordinate measuring machine.</p> <p>The slider increments are forced to integer precision so it is not possible to move to sub millimeter locations for any axis. This is intentional as it is easier to see the calculated compensation errors which are typically less than 1 mm.</p>
<p>X Uncomp: <b>789.0000</b></p> <p>Y Uncomp: <b>618.0000</b></p> <p>Z Uncomp: <b>-757.0000</b></p>	<p>Position of the machine prior to compensation. These values are defined by the axis sliders to the nearest millimeter.</p>
<p>X Comp: <b>788.9998</b></p> <p>Y Comp: <b>618.5495</b></p> <p>Z Comp: <b>-757.0000</b></p>	<p>Compensated position of the machine.</p> <p>The probe offsets are always included in calculated position even if the option 'Include Probe Offset in DRO' is not checked.</p>
<p><input type="checkbox"/> Include Probe Offset in DRO</p>	<p>The compensated and uncompensated coordinate display readouts will include the offset of the probe if this option is checked.</p>
<p><input checked="" type="checkbox"/> Update Limits from Error Map</p>	<p>When a compensation map file is loaded the Minimum, Maximum, and Step values for each axis will be automatically changed to match the compensation file if this option is checked.</p>
<p>Show Record Dialog</p> <p>Show Playback Dialog</p> <p>Show Error Display</p>	<p>Options useful for testing and visualization. These options are described in more detail in the sections below.</p>
<p>Kinematic: <input type="text" value="YXZ"/></p>	<p>Selection of the kinematic axis order. This option is set automatically when the file is loaded but can be overwritten to any supported axis order.</p>

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<i>Item</i>	<i>Description</i>
<p>X Errors:</p> <ul style="list-style-type: none"><li><input type="checkbox"/> LXX</li><li><input type="checkbox"/> LXY</li><li><input type="checkbox"/> LXZ</li><li><input type="checkbox"/> RXX</li><li><input type="checkbox"/> RXY</li><li><input type="checkbox"/> RXZ</li></ul>	<p>Options to enable or disable specific errors from the loaded compensation error map. When checked, the option is active.</p> <p><i>Toggleing individual error map options with a 3D model active is a good way to visualize how that particular parameter is interpreted.</i></p>
<p>Close</p>	<p>Close the program.</p>

### Compensation Map Information

The active compensation error map has additional information that can be shown or hidden with the *Show Map Details / Hide Map Details* button. The following is an example of the type of information displayed from a loaded compensation error map:

```
INFO: Map loaded '/Users/ron/Desktop/Errc-horizontal arm/'
LK Compensation Map
```

Attributes:

```
Binary File: 1
Ascii File: 0
Rotary Axis: 0
Encrypted: 0
Signed Map: 0
Vertical: 0
Horizontal: 1
Kinematic: XZY
```

Axis Data:

```
X Data Size: 31 Optional Parameter Count: 0
Y Data Size: 25 Optional Parameter Count: 0
Z Data Size: 25 Optional Parameter Count: 0
A Data Size: 0 Optional Parameter Count: 0
B Data Size: 0 Optional Parameter Count: 0
```

Axis Range:

```
X -2800.000 to 200.000 mm
Y -1200.000 to 0.000 mm
Z -50.000 to 1150.000 mm
```

Additional Files:

```
Deflection file ZCRS Loaded with map
```

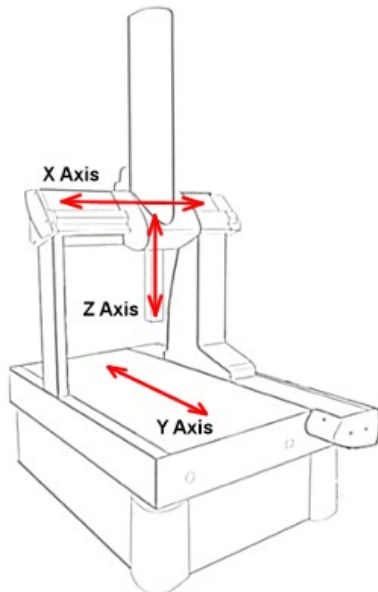
The first lines of the information window show the name and type of compensation data. The attributes section describe various details about the data and how it is formatted. The five possible axis parameters are listed with the number of elements for each followed by the range for each non-zero axis.

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## Kinematic Axis Order

The kinematic axis order describes how the three axis of a coordinate measuring machine are connected to each other. A typical bridge CMM will have the Y axis travel along a fixed base and this becomes the supporting frame for the X axis. The Z is connected to the X and the probe is mounted at the bottom of the Z. The kinematic axis order of the CMM shown in illustration 2 would be YXZ since the Y axis is the first moving axis, the X is connected to the Y, and Z is connected to the X.



*Illustration 2: Example of a machine with a kinematic axis order of YXZ.*

Some compensation error maps include the kinematic order as part of the compensation data while others rely on settings inside the inspection software to decide how to interpret the data. When the kinematic order is not defined in the map other supporting files are considered.

When a compensation error map is loaded the kinematic order will default to the option defined by the error map. The kinematic order can be changed to any of the supported formats after loading the compensation file even if the file doesn't natively support the selected kinematic order.

The common kinematic axis orders for bridge machines are XYZ and YXZ. For horizontal arm CMM's the kinematic order commonly used is XZY but YZX is also supported. The Error Map Explorer utility supports axis orders of XYZ, YXZ, XZY, and YZX. Any combination of axis can be used but only certain combinations seem to appeal to general use.

*Compensation error maps that were never intended to be used with certain kinematic axis orders will still work in the Error Map Explorer utility.*

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## Visual Display of Errors

The button *Show Error Display* will open a window that visually displays the effect of the active error compensation. The display includes a simulated CMM that is partially transparent and is animated with the axis sliders.

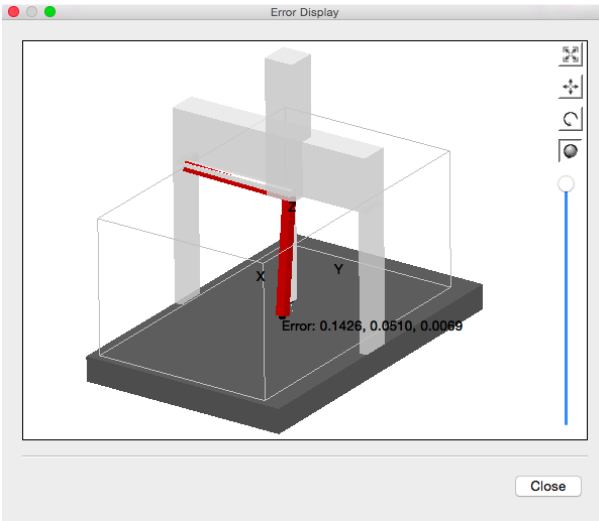


Figure 1: Example of a combination of angular errors from a CMM compensation error map.

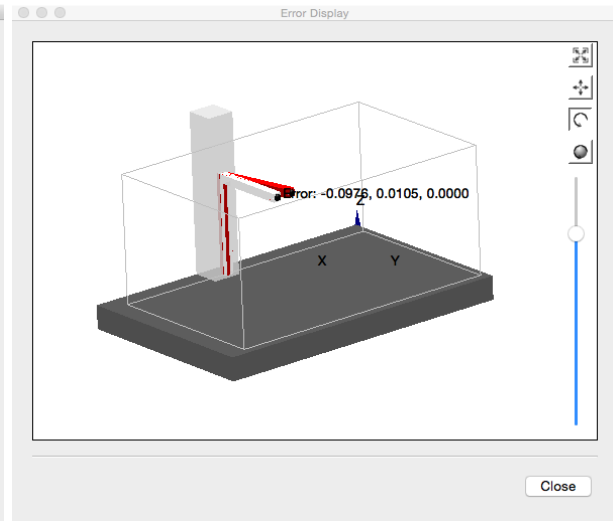


Figure 2: Example of a correction for the XY squareness for a horizontal arm CMM.

The moving axis of the machine are shown in grey and the effect of the compensation is displayed in a red frame. Both the nominal machine and the error have a probe mounted on the end of the axis. The amount of correction that is applied is displayed at the position of the stylus tip.

*The method used to exaggerate the error is not a true representation particularly for angular data. The linear effect of the exaggerated error is always correct.*



## Visual Display Controls

The Error Display window is not fixed and can be manipulated in a variety of ways. The kinematic axis model is displayed on the idea of a projection frustum to mimic the relative size of objects based on the distance away from the viewer to provide a slightly more realistic rendering of the volume of the data.

Image	Description
	Scale to fit. Adjusts the scale of the OpenGL Projection matrix to fit the visible data into the display viewport.
	Pan Mode. When enabled a right mouse button click and drag will move the position of the displayed model. For systems with a single mouse button use Ctrl + Mouse.
	Rotate 2D Mode. When enabled a right mouse button click and drag will rotate the model around the center of the viewport. For systems with a single mouse button use Ctrl + Mouse.



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Image	Description
	Rotate 3D Mode. When enabled a right mouse button click and drag will rotate the model around the click position on the displayed model. For systems with a single mouse button use Ctrl + Mouse.
	Error Multiplier. The relative error of the data can be increased with this slider. <i>The error multiplier will allow compensation errors to be exaggerated. Increasing the magnification increases the effect of the compensation map errors on the red kinematic machine model.</i>

In addition to the above controls areas of the kinematic model can be zoomed by drawing a box around any area of interest. The scale of the model can be increased or decreased using the mouse scroll button.

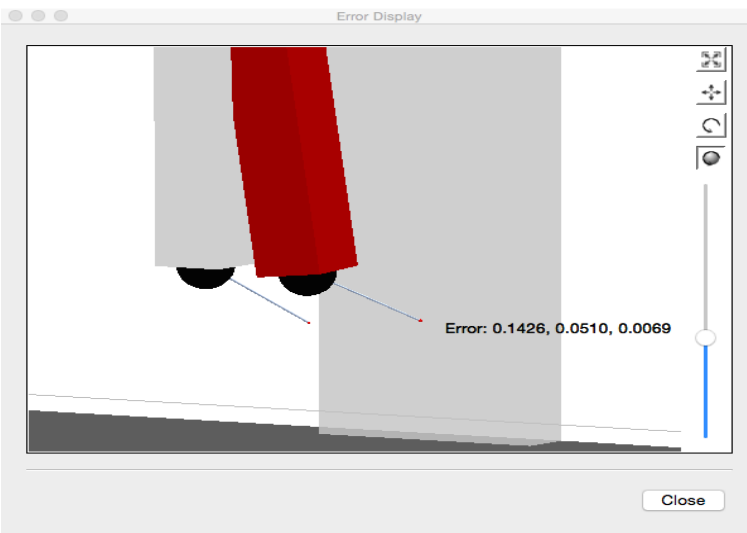


Illustration 3: Example showing the probe offset and error correction value at probe.

## OpenGL

The error display data is drawn using OpenGL. The computer must have at least OpenGL version 2.x or higher in order to run this utility program with a functional visual display of the data.

Running the Error Map Explorer program on computers that only support OpenGL 1.x the visual display is replaced with an information window. An example of this information window is shown in illustration 4.

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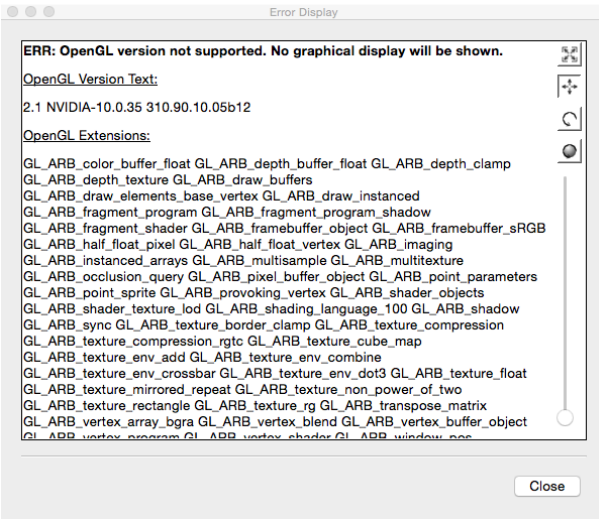


Illustration 4: Information screen that is displayed with unsupported OpenGL versions.

## Record Sequence Dialog

The button *Show Record Dialog* will open a window that allows the user to create a file containing individual test positions that can be played back at a later date. The recorded information includes the actual error correction applied for each position and all related settings and is used as a comparison value for future tests. This information can be used for semi automatic validation tests of implementation methods of different compensation software.

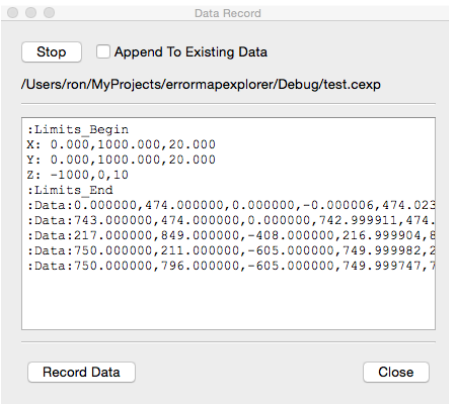


Illustration 5: Record data dialog showing captured information.

Option	Comments
Start / Stop	Start or stop the process of creating a sequence test file. When started a file dialog will appear allowing the user to input the name of the file to create or append to.

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<i>Option</i>	<i>Comments</i>
Append to Existing Data	If checked the new data will be added to the end of of an existing file.
Record Data	Store the current parameters as a file entry. Each entry is created by clicking on this button.
Close	Close the record dialog and any open files.

### Sequence File Data Format

The format of the file is text. The first section of the text file is expected to contain the data for the axis limits. Each subsequent line contains one entire set of data. The last value in each data line is an integer bit mask for all program options.

The following is an example of a record file:

```
:Limits_Begin
X: 0.000,1000.000,100.000
Y: 0.000,1000.000,100.000
Z: 0.000,1000.000,100.000
:Limits_End
:Data:1000.0,1000.0,1000.0,1000.0,1000.0,1000.0,0.0,0.0,0.0,134217736
:Data:1000.0,1000.0,1000.0,1000.0,1000.0,1000.0,500.0,0.0,0.0,134217736
:Data:1000.0,1000.0,1000.0,1000.0,999.9998,1000.500,0.0,500.0,0.0,134217736
```

Where:

```
:Limits_Begin    Beginning of the limits section of the sequence file.
:Limits_End      End of the section containing the axis limits.
X:               defines the minimum, maximum, and step size for the X axis.
Y:               defines the minimum, maximum, and step size for the Y axis.
Z:               defines the minimum, maximum, and step size for the Z axis.
:Data            <uncompensated>,<compensated>,<probe>,<flags>
```

Where:

```
<uncompensated>  comma separated XYZ values showing the uncompensated machine position
<compensated>    comma separated XYZ values showing the compensated machine position
<probe>          comma separated XYZ values for the active probe offset
<flags>          integer value for enabled options.  LXX=0b1, LXY=0b01, LXZ=0b001, ...
```

The extension used for the record file is *CEXP*.

### Playback Dialog

The button *Show Playback Dialog* will show a window that is designed to execute sequence files. The playback can be step by step or automatically from start to finish. When playing all steps automatically there is a one second delay between steps to allow for viewing.

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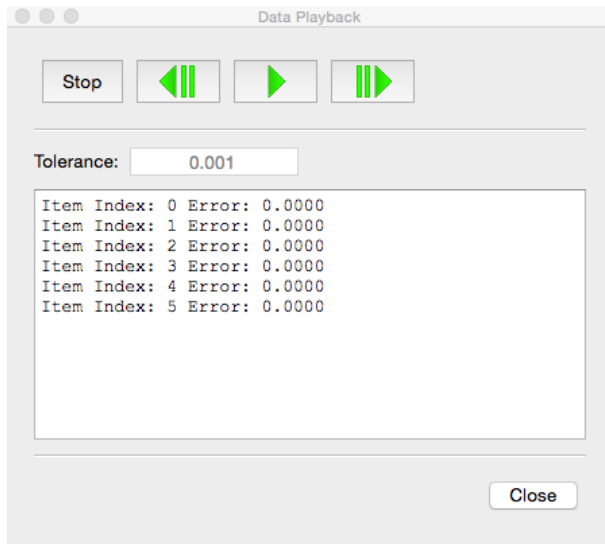




Illustration 6: Playback dialog. Each step will update the program based on the information from the record file.

Option	Comments
Start / Stop	Start or stop the process of of playing back a record sequence file.
Tolerance	Amount of error permitted between the errors from the record sequence file to the active data. When the tolerance is exceeded the entry in the log will show a series of asterisks on the end of the data line.
	Backward and forward buttons. These options allow the manual stepping through all the data in the playback sequence in either direction.
	Play all steps. The data is played back from the beginning to the end. Each step is automatically paused for one second allowing for quick review.
Close	Close the playback dialog.

## Correction Examples

The following shows the effect of different types of compensation with a CMM.

### Horizontal Arm (XZY) X Axis Roll

The X axis roll on a horizontal arm CMM is a description of the twist in the X axis of the machine. The X axis roll changes the direction of the Z and Y axis. As the X axis position changes the Z and Y axis direction are simultaneously changed based on the X axis roll.

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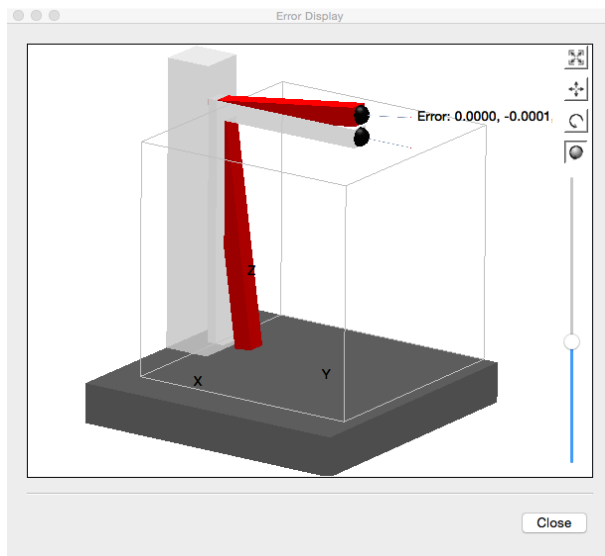


Figure 3: Example of the X axis roll on a horizontal arm CMM

The rotation point for the correction is an implementation detail. The mechanical rotation point is always at the bottom of the Z axis where the physical rotation occurs. The zero point of the compensation map is usually at the top of the Z axis and this is frequently used as the calculation point by the software.

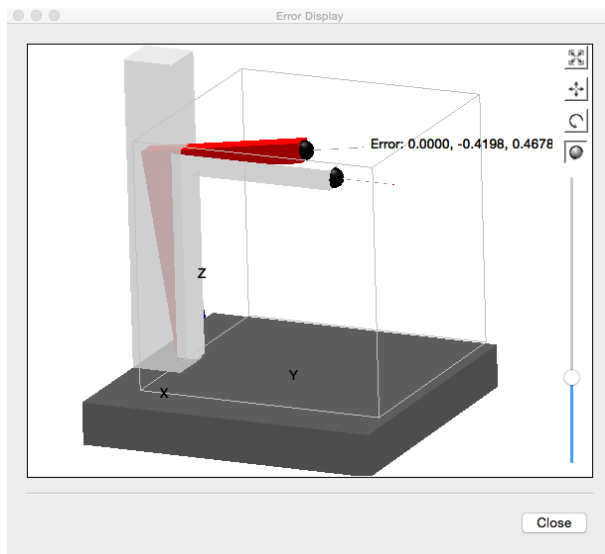


Figure 4: Horizontal arm rotation point at base of arm. The correction mimics the real change in the machine.

Figure 3 shows the correction for the X axis roll when calculated from the compensation maps zero position. Figure 4 shows the correction when the compensation map calculations are performed from the base of the Z axis ignoring the zero position. The two methods both work but yield very different results for the affected linear data.

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*This is a good example of why conversion between different types of compensation error map formats should be avoided.*

### Vertical Arm (YXZ) Y Axis Roll

The Y axis roll on a vertical arm CMM is a description of the twist in the Y axis of the machine.

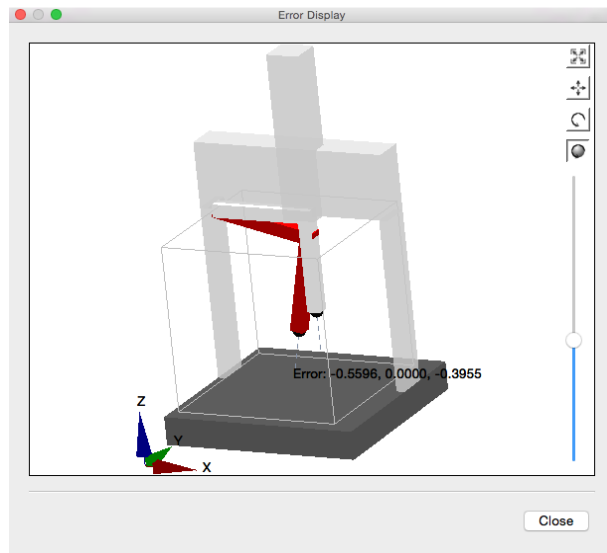


Figure 5: Compensation for Y axis roll on a vertical arm CMM

The calculation point for rotations of the first axis of a bridge machine can be anywhere with no obvious advantage of one position over any other. The choice of the rotation point will affect all the linear data for this axis. The rotation center commonly used is the top / left side of the machine (compensation map zero position).

### Vertical Arm (YXZ) Y Axis Yaw

The Y axis yaw on a vertical arm CMM is a description of the Y axis rotation around the Z axis of the machine. When viewed from the top of the machine it is a good example of abbe error.

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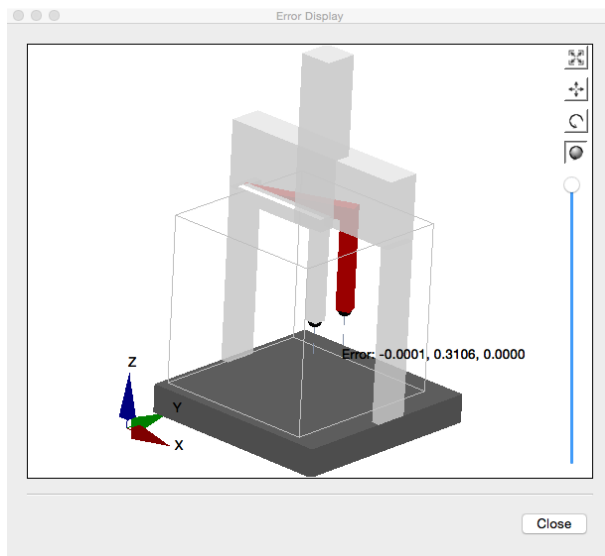


Figure 6: Compensation for Y axis yaw on a vertical arm CMM

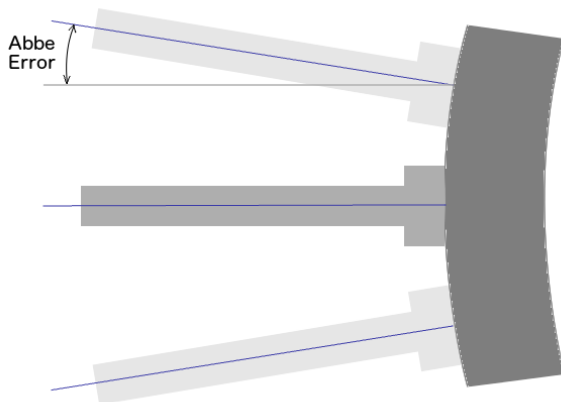


Figure 7: Error when viewing from the top of the CMM.

The correction for this error is frequently calculated from the map zero position which is often opposite of the guideway that defines this error. For machines that use certified scales such as laser interferometers instead of standard scales such as tape or etched glass this can be a bit of a problem unless the rotation center is calculated from the position of the scale. This correction is another example where the implementation used by different vendors differs where some compensation maps include offsets back to the scale position where others include non-standard rotation points that can be set anywhere inside the machine volume.

*Using a non-standard rotation position has advantages in some cases particularly for data collection.*

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### Revision History

<i>Date</i>	<i>Version</i>	<i>Changes</i>
June 7, 2017	1.0	New Program
Nov 3, 2017	1.1	Interpretation change for LK horizontal arm CMM's. Fixed problem loading DEA type 4 maps with incomplete fourth axis header data.
Feb 18, 2017	1.2	Updated interpretation of maps with corrections such as a fourth axis or dual scale.
Apr 25, 2018	1.3	Added support for VDMIS compensation files.
Oct 24, 2018	1.4	Added support for Zeiss Guideway/Square compensation files.
Nov 17, 2018	2.0	Fixed problem with interpretation of dual axis maps. Fixed incorrect name for graphics display button. Added simulation of machine with data Improved routines for path shapes to remove joint artifacts. Added map information screen.
Jan 28, 2019	2.1	Added Mycrona map format Added Visio map format