Error Map Explorer Users Guide

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Introduction

The *Error Map Explorer* is a utility that can calculate corrections based on data from a compensation error map and produce numerical and graphical results. The correction values are calculated to the position of the active tool stylus tip and is comparable to methods used by most CMM's.

The *Error Map Explorer* can load compensation data from a variety of sources. The sample error map file is provided with this utility can be used if access to map data is not available. A sample test sequence file is also available in order to demonstrate the capabilities.

The correction calculated from the compensation map data can be difficult to visualize particular if more than one parameter is active at any given time. To make this part easier individual errors or combinations of errors can be activated or deactivated showing the impact immediately. Without this feature it would be necessary to create a series of compensation map data files containing specific parameters or combinations of parameters and load them one at a time.

Test sequences can be recorded and repeated for automated comparison of data. This feature was added for testing where many combinations of errors and probe offsets are needed to fully evaluate a compensation error map and is particularly useful for testing unknown compensation methods used by third parties. One particularly useful aspect is when internal changes to the map interpretation library was made as this allows a method to validate the changes.

The interpretation of the compensation error map data matches those used by the manufacturer for standard kinematic configurations. 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.

The *Error Map Explorer* also demonstrates why conversion of compensation error map data from one format to another is a bad idea even after taking into account sign conventions and other common differences. One example is a DEA horizontal arm compensation map as compared to a BnS equivalent where, after taking into account sign conventions, there will be a significant difference between the two even if the map data is identical and have the same kinematic axis order. The difference is simply due to implementation differences.

Overview

The *Error Map Explorer* can load a compensation map from any supported format. The simulated machine can be driven to any location within the machine volume showing both visual and numerical feedback to the amount of compensation applied at the point of the tool tip. The central view of the E*rror Map Explorer* is a simulated CMM that can be setup for any supported kinematic configuration.

The machine parameters and machine position are shown on the left side of the main window. The uncompensated position of the simulated CMM is locked to integer values which improves the readability of the compensated data. The options allows for customization of the *Error Map Explorer* when loading compensation data.

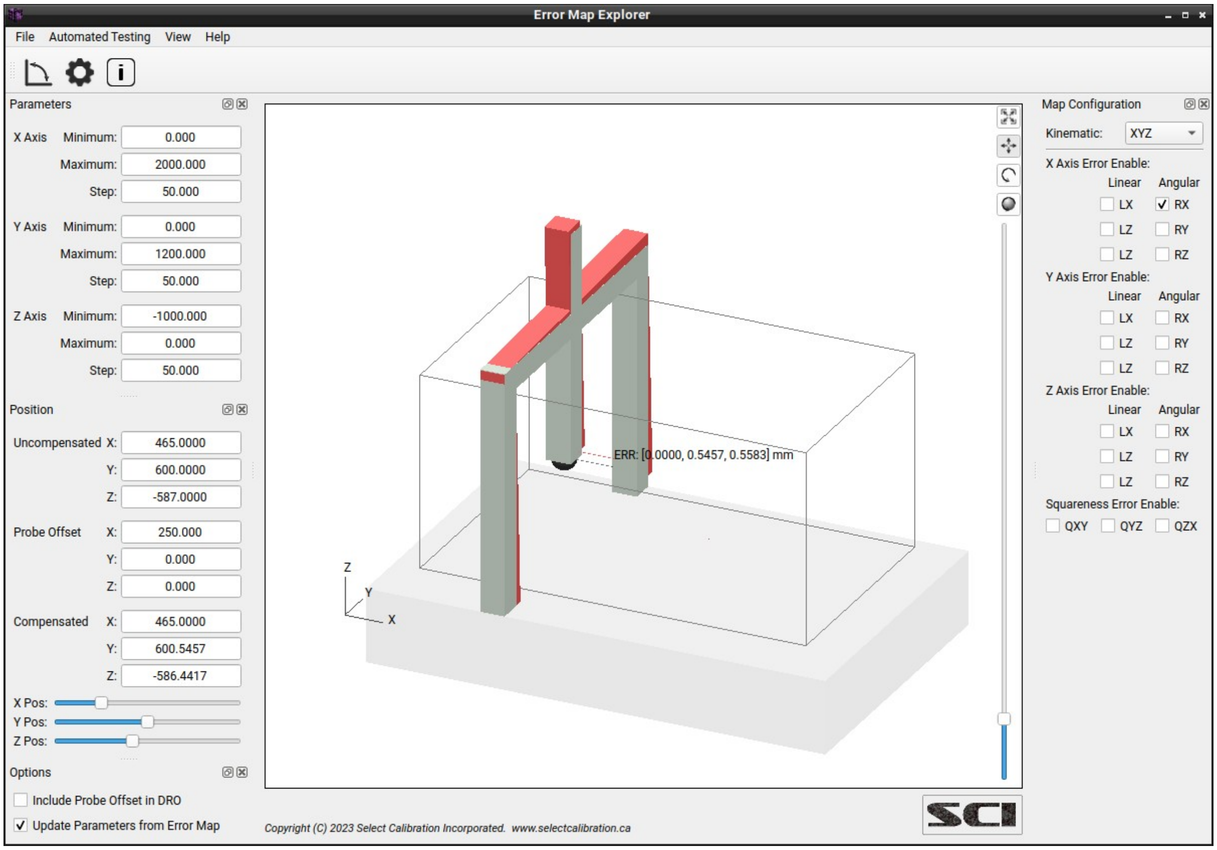
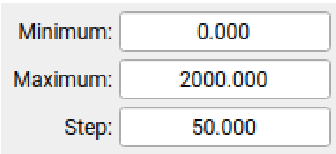
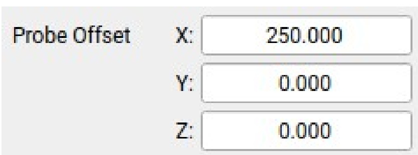
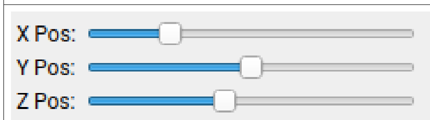
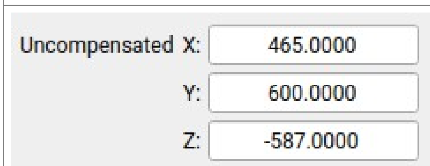
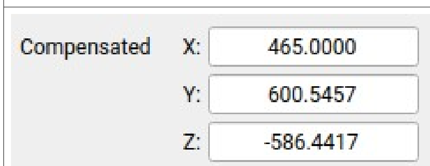
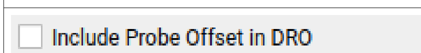
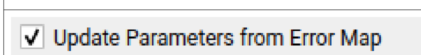
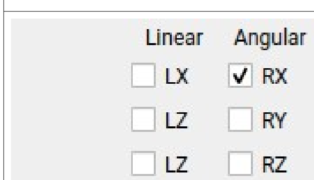


Illustration 1: Main window of the Error Map Explorer with a map loaded and a single compensation parameter active.

Menu Options:

Item	*Description*
Open Compensation File	Load the error map. The error map can be of any supported format. *Compensation maps can be loaded by dragging and dropping onto the Error Map Explorer utility.*
Compensation Map Information	Display information about the loaded compensation file. See Compensation Map Information section below.
Quit	Close the *Error Map Explorer* utility.
Sequence Editor	Show the Sequence Editor dialog. See Sequence Editor section below.
View	Show or hide the various dockable widgets used by the *Error Map Explorer* utility.
About	Information about the *Error Map Explorer* utility.

Left Side Widget Options:

Item	*Description*
	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. *The step value is set to the absolute increment value of the map axis. This value controls the step size of the axis sliders.*
	Probe offset of the tool attached to the last axis of the CMM. The correction is calculated to the center of the probe stylus defined by this offset.
	Sliders used to position the simulated coordinate measuring machine.
	Position of the machine prior to compensation. These values are defined by the axis sliders to the nearest millimeter. Editing these fields will update the axis position sliders.
	Compensated position of the machine. *The probe offsets are always included in calculated position even if the option 'Include Probe Offset in DRO' is not checked.*
	The compensated and uncompensated coordinate display readouts will include the offset of the probe if this option is checked.
	When a compensation map file is loaded the Minimum, Maximum, and Step values for each axis will be updated to match those of the compensation data if enabled.
	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.
	Options to enable or disable specific errors from the loaded compensation error map. When checked, the option is active for each displayed axis.

Compensation Map Information

Additional information from the active compensation error map can be displayed by selecting *Compensation Map Information* from the file menu. The following is an example of the type of information that is 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.

Supplemental Compensation Map Data

Compensation error maps that have supplemental data, such as BnS CT2 map with deflection parameters or horizontal arm deflection data, do not show the result of this extra compensation in the *Error Map Explorer* utility. Only the standard 21 compensation parameters that are listed in the *Map Configuration* window can be activated.

Compensation maps configured with dual scale or dual axis such as a DEA-4 with left and right X axis data will make use of the second axis data when calculating corrections. Typically for machines with this configuration the role of the first axis yaw compensation (X axis rotation around Z) would be handled solely by the left and right scales with only the weighted average used for error calculation based on the probe offset. Illustration 2 shows an example of a dual axis DEA-4 map and the resulting correction based on the yaw error only showing only the probe being corrected.

Compensation from the supplemental data may be added in the future if it makes sense to do so.

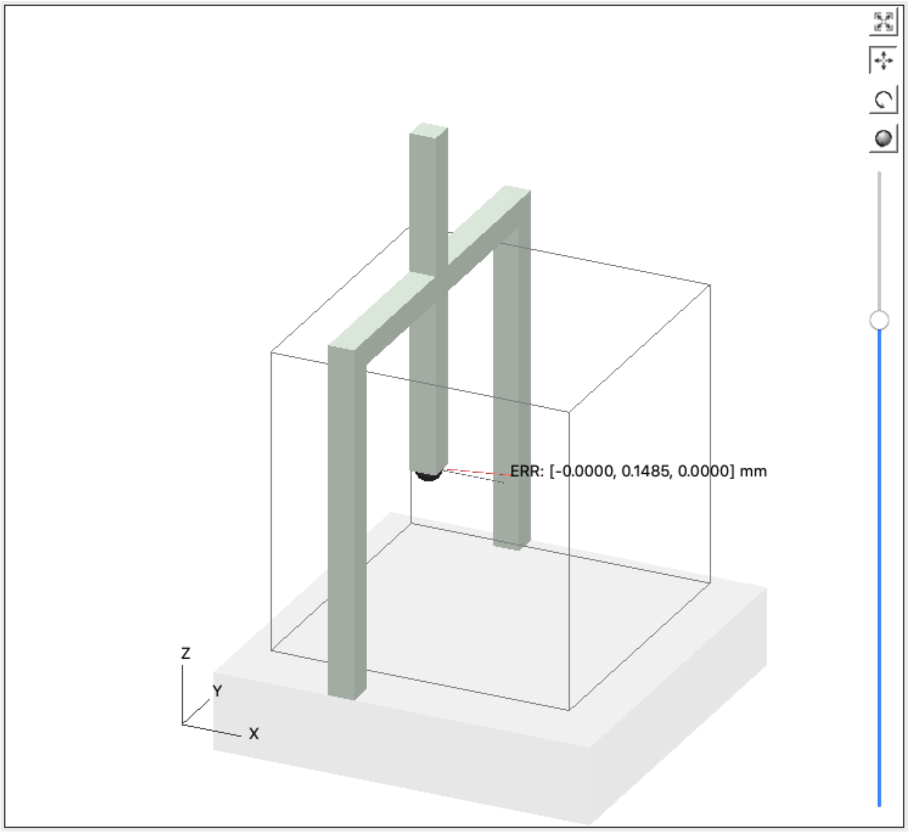


Illustration 2: Compensation result from a DEA-4 machine with separate left and right scales. Only the probe is corrected based on yaw errors.

Activation of any dual axis parameter, even if not displayed as a separate left and right axis option, applies to both.

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 3 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.

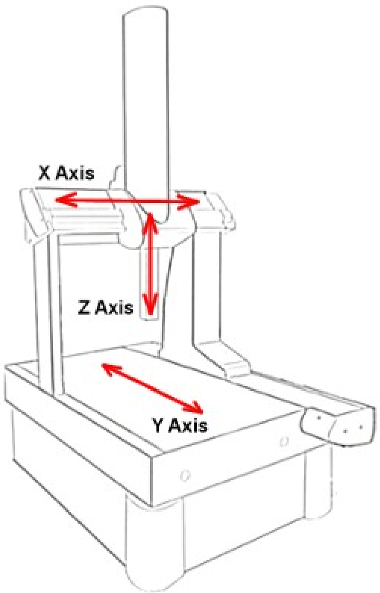


Illustration 3: Example of a machine with a kinematic axis order of YXZ.

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 then other supporting files are considered or a default selection is used. The kinematic order can be changed to any of the supported formats after loading the compensation file even if the file doesn't naively 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 kinematic configurations of XYZ, YXZ, XZY, and YZX. Although any combination of axis can be used only certain combinations appeal to general use so finding a CMM in the field configured with a kinematic of YZX or setup with X as the vertical axis is something unlikely to be encountered.

Compensation error maps that were never intended to be used with certain kinematic axis orders will still work in the Error Map Explorer utility. The corrections are calculated using generic routines in those cases.

OpenGL Display

The display of the 3D model is not fixed and can be manipulated in a variety of ways:

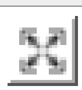
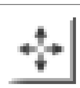
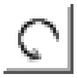
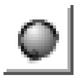
Image	*Description*
	Scale to fit. Adjusts the scale of the OpenGL Projection matrix to fit the visible data into the display viewport.
	Pan Mode. When enabled a right mouse button click and drag will move the position of the displayed model. For systems with a single mouse button use Ctrl + Mouse.

Image	*Description*
	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.
	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. *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.*

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

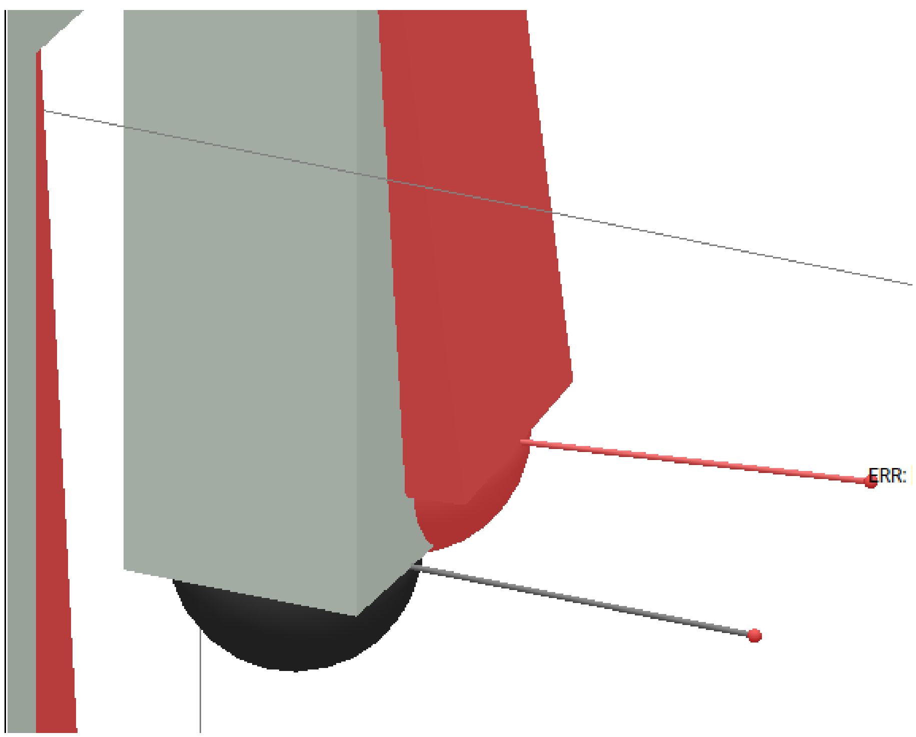


Illustration 4: Example showing the probe offset and error correction value at probe.

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 model display is replaced with an information window. An example of this information window is shown in illustration 5.

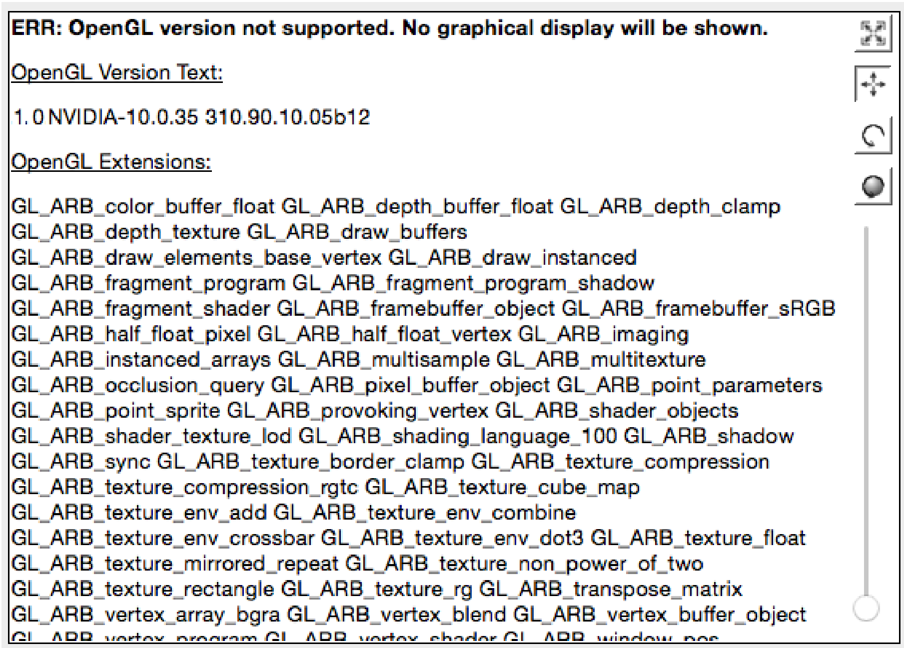


Illustration 5: Information screen that is displayed with unsupported OpenGL versions.

Sequence Editor

The *Sequence Editor* allows for automatic comparison testing to other compensation maps or the same error map with various changes in the data or setup. This information can be used for automatic validation tests of implementation methods or other relevant map interpretation details.

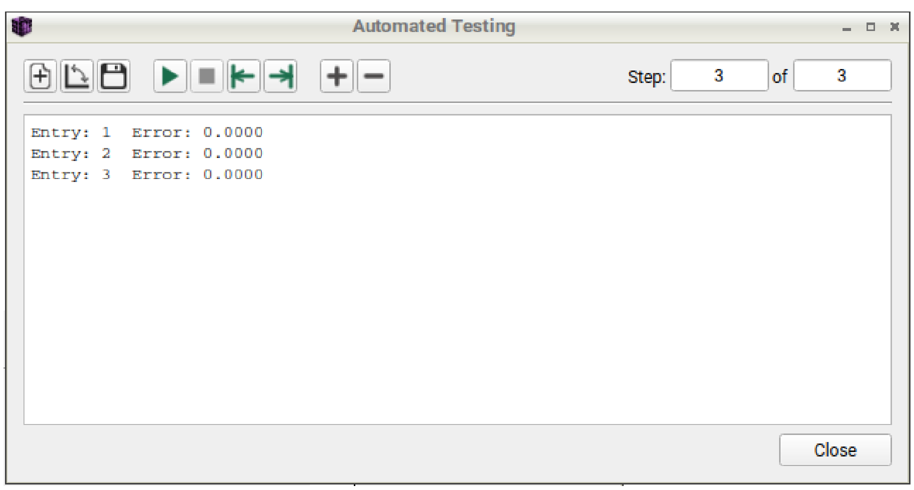
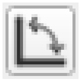
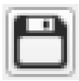
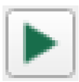
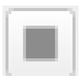
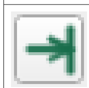
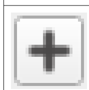
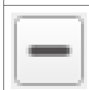


Illustration 6: Sequence editor dialog showing results of captured information.

Menu Options:

Option	*Comments*
	Clear all existing sequence data.
	Open an existing sequence data file.
	Save the current sequence steps to a file.
	Execute the current sequence steps.
	Stop execution of the sequence.
	Manually step to previous sequence step.
	Manually step to next sequence step.
	Insert a new sequence step using current data.
	Remove the current sequence step.

Sequence File Data Format

The format of the file is text. The first line must identify the file as a sequence file followed by data for the axis limits. Subsequent lines starting with ':Data:' contain entries for each position, tool offsets, and expected correction error at the position of the tool tip.

The following is an example of a sequence file:

```
AutomatedTesting:Version=1:Type=Sequence
: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:297,493,-537,296.999956,493.148500,-537,250,0,0,2097152,512
:Data:726,493,-537,725.999999,493.024000,-537,250,0,0,2097152,512
:Data:726,63,-537,725.999999,63.024000,-537,250,0,0,2097152,512
```

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
<flag1>          integer value for enabled options.
<flag2>          integer value for enabled options.
```

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

Visual Correction Examples

The following shows examples of various compensation parameters for different configurations of CMM's.

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.

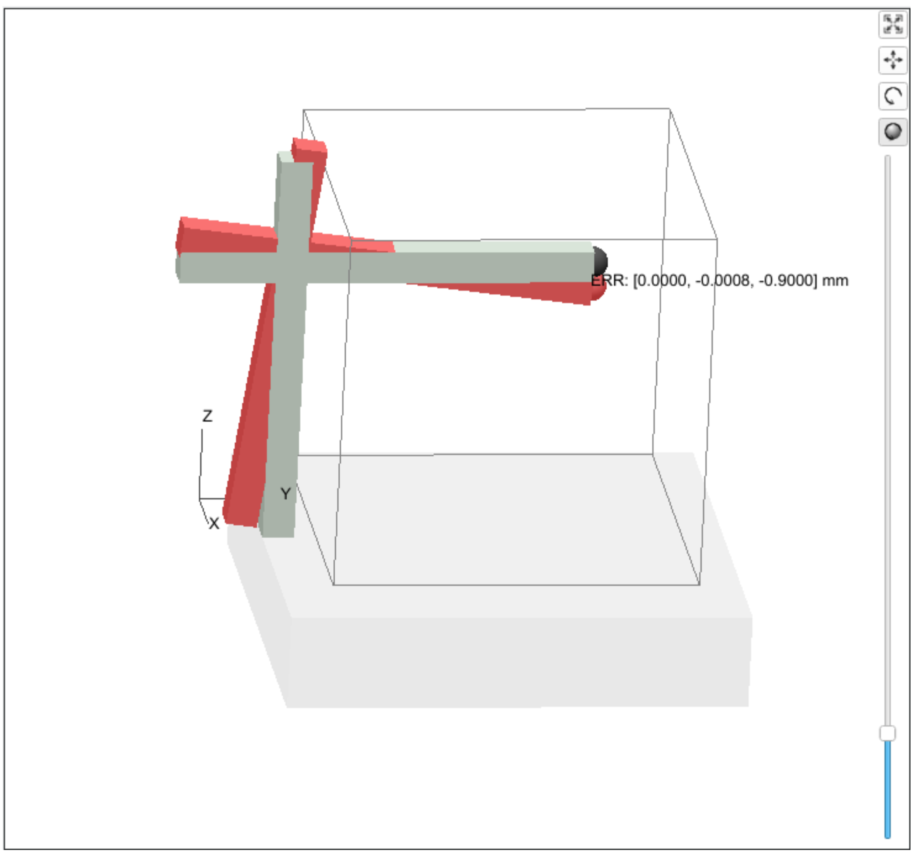


Illustration 7: Example of the X axis roll on a horizontal arm CMM with a BnS CT2 compensation error map.

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.

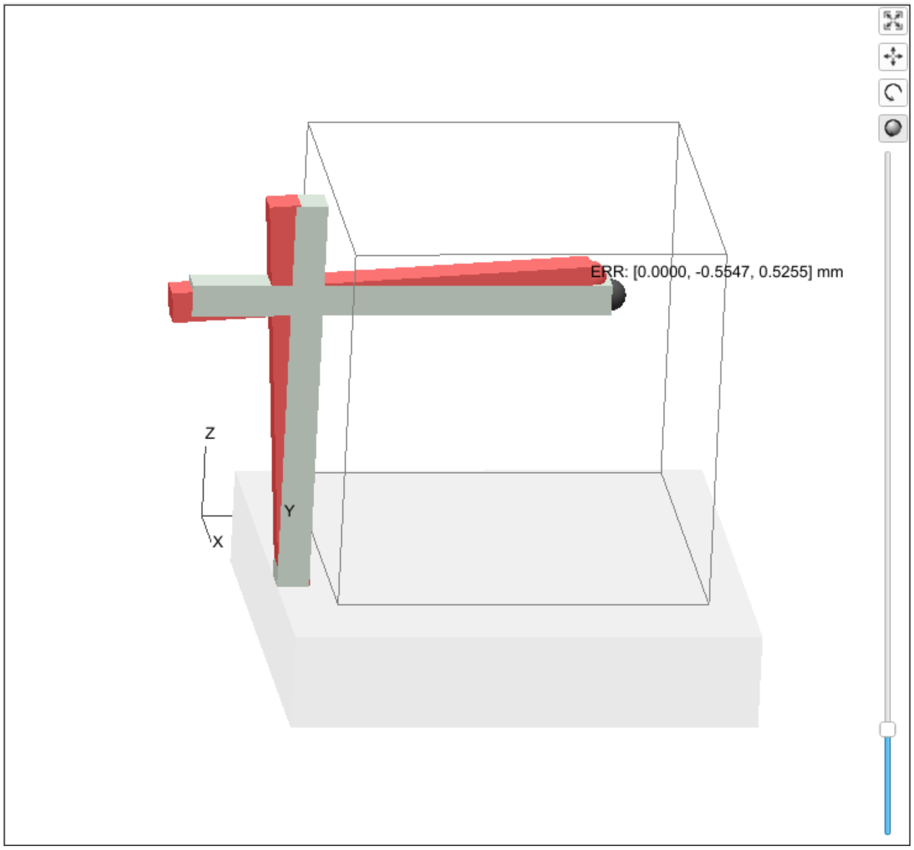


Illustration 8: Example of the X axis roll on a horizontal arm CMM with a DEA-1 compensation error map.

Illustration 7 shows how the compensation is applied when calculated from the map zero position where illustration 8 shows compensation calculated from the mechanical rotation point (the bottom of the Z axis in this case). The two methods both work but yield very different results for impacted linear data; straightness in particular.

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. 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 rotation center commonly used is the top / left side of the machine (compensation map zero position).

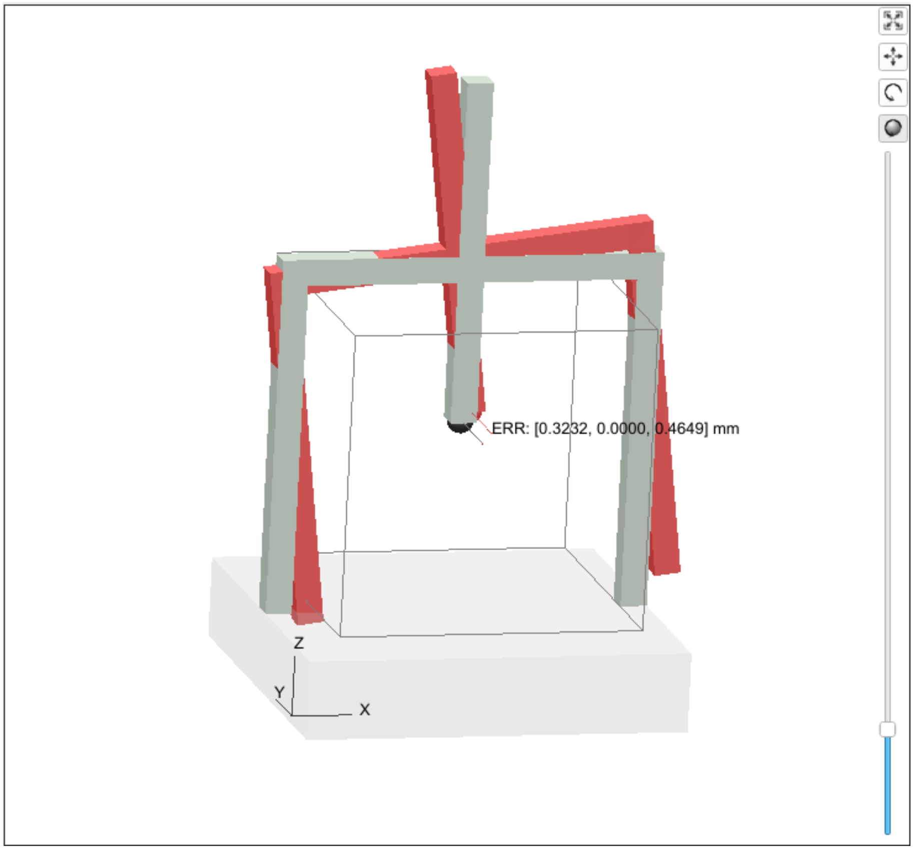


Illustration 9: Compensation for Y axis roll on a vertical arm CMM with a BnS CT2 compensation error map.

The choice of the rotation point will affect all the linear data for this axis. In the example shown in illustration 9 the rotation point is not at the top / left edge of the bridge since the map used is a BnS CT2 with a zero point that is not at the top / left edge (a typical configuration for a BnS CT2 vertical arm CMM error map).

Illustration 10 shows a DEA-1 compensation map forced to a kinematic of YXZ showing the same kind of error as displayed in illustration 9. Unlike the BnS CT2 maps that have both a positive and negative component to each axis the DEA maps only have one axis direction and are always configured to start at the top / left / back edge of the machine volume. The rotation point is different between these two examples as a result. Both methods both work but will result in different straightness errors along the Y axis.

DEA does not support a kinematic chain of YXZ and BnS does not support a kinematic chain of XYZ. The DEA map was forced to a kinematic of YXZ for demonstration purposes.

The two examples above show another reason why conversion between different map types is a bad idea. It is theoretically possible to properly convert between different compensation map types and retain accuracy but it is far more involved than simply transferring the data from one map type to another.

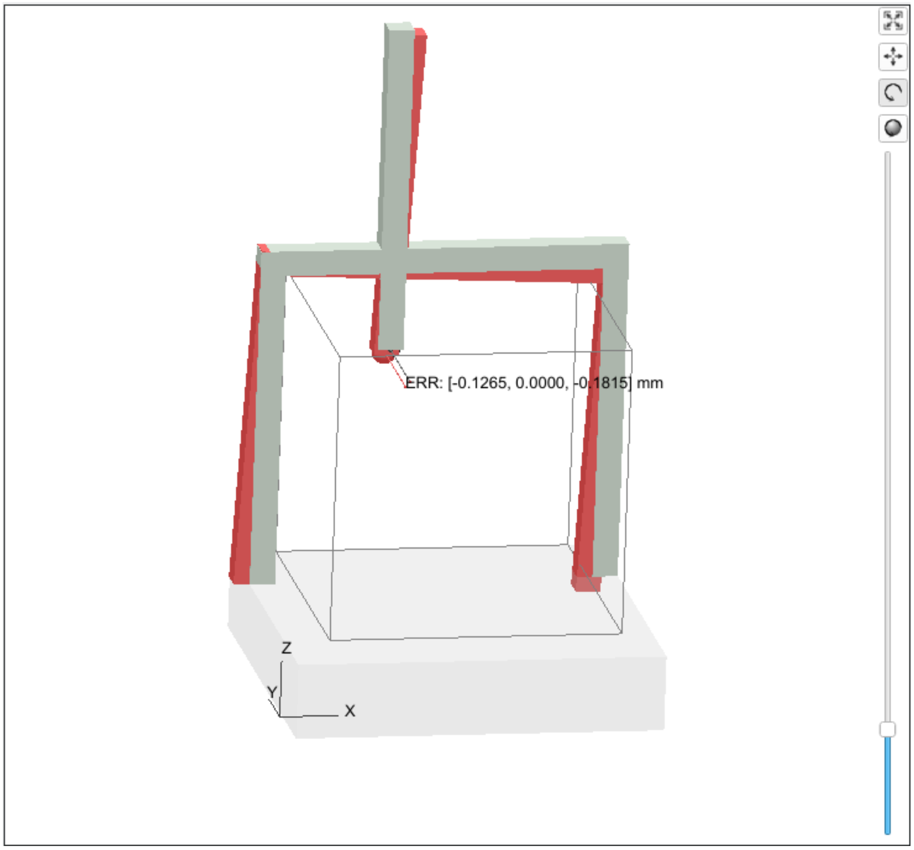


Illustration 10: Compensation for Y axis roll on a vertical arm CMM with a DEA-1 compensation error map.

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.

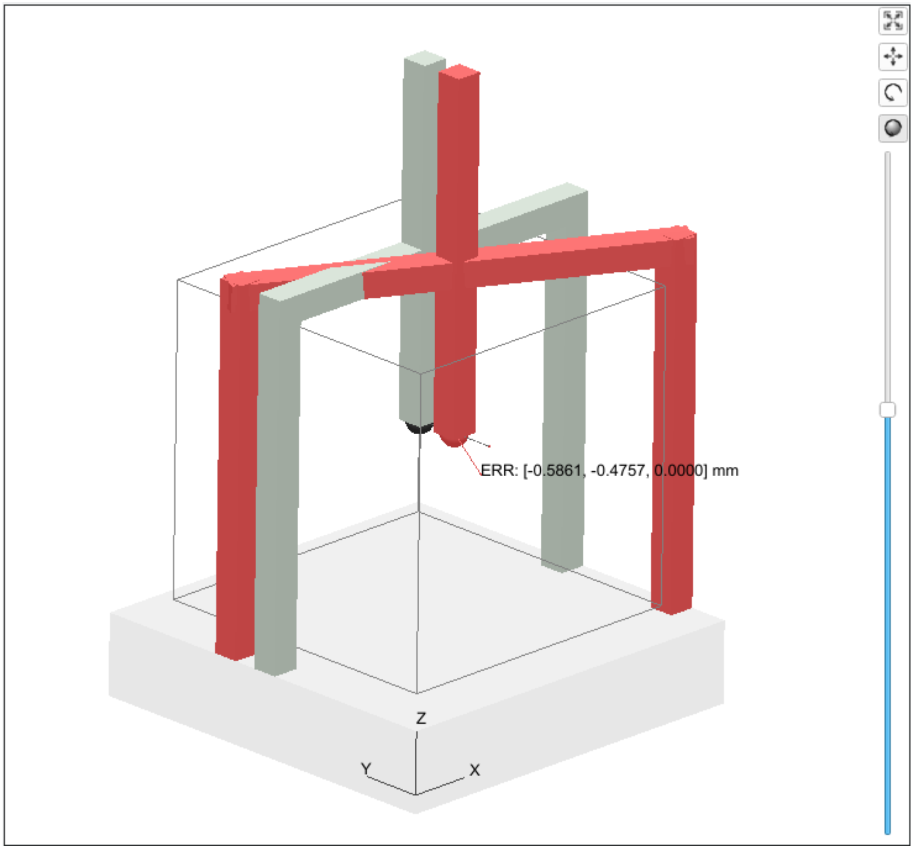


Illustration 11: Compensation for Y axis yaw on a vertical arm CMM with a BnS CT2 compensation error map.

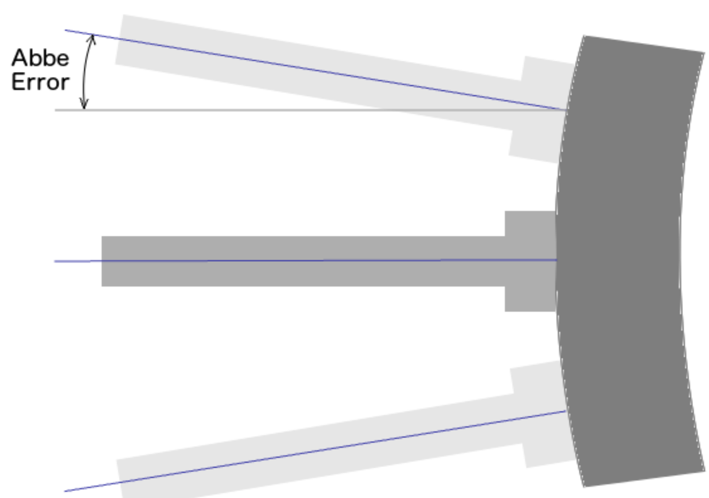


Illustration 12: Abbe error when viewing from the top of the CMM. The right side of the image is the drive side of the CMM.

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.

Revision History

Date	*Version*	*Changes*
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 support for Mycrona compensation files Added support for Visio compensation files
Sep 9, 2019	2.2	Change in deflection format for BnS CT1 and CT2 maps.
Feb 7, 2020	3.0	Added support for Metrolog type 2 compensation files Added support for Metrolog type 3 compensation files
Apr 17, 2020	3.1	Added ability to directly enter XYZ coordinate positions. Updated sign hints for Renishaw compensation files. Updated resource files.
Dec 11, 2023	4.0	Redesign of user interface. Redesign of sequence editor. Update of OpenGL display.