# Error Simulator Users Guide

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## Introduction

The *Error Simulator* utility allows simulated CMM measurements of various artifacts in order to assist in the development of tools and procedures necessary for efficient calibration of coordinate measuring machines. Developing methods to extract specific machine errors from measurements require accurate test data so that methods can be evaluated properly. Using a real CMM can be problematic as physically changing the shape of the machine in order to test different scenarios is not possible in many cases and measurement noise can bias data.

The *Error Simulator* utility can simulate a variety of machine errors on CMM's with various kinematic configurations including tower deflection for horizontal arm CMM's. In addition to providing test data for tool development the *Error Simulator* utility was also intended to perform automatic comparison testing of different measurement strategies for CMM performance testing.

The measurement positions can include variables for dynamic adjustment of size and location to suite the target machines measurement volume. If the measurement setup is as intended no changes to the measurements would be required when switching between different machine configurations or dimensions.

## Overview

The *Error Simulator* utility consists of a main window and two dockable widgets for the machines and measurements. Illustration 1 shows the main window of the *Error Simulator* utility.

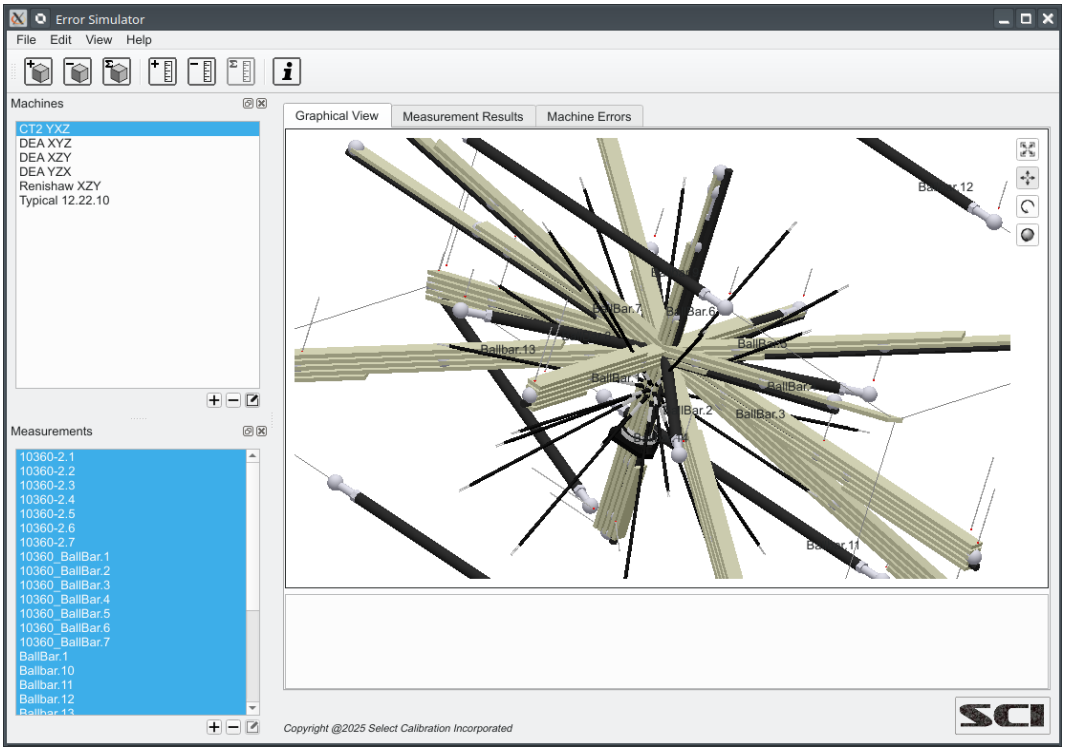



*Illustration 1: Main view from the Error Simulator utility showing a graphical view of various measurements inside the volume of a selected machine.*

## Graphical View

This view shows a 3D representation of the measurement volume for the active machine and all selected measurements. Measurement items displayed inside the graphical view will report individual results when clicked with the left mouse button. The selected measurement item will be highlighted and the text of the measurement will appear in the section below the graphical window.

*A machine must be selected in order to display one or more measurements in the graphical view.*

### Graphical View 3D Controls

The 3D model display is not fixed and can be manipulated in a variety of ways. The volume of the selected machine is displayed as a wire cube.

*Table 1: Options:*

| *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. |
|  | 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. |

### OpenGL

The graphical view of the measurement data is drawn using OpenGL. The computer must support OpenGL version 2.x or higher in order to run this utility program with a functional 3D view of the measurement data.

Running the CMM Error Simulator program on computers that only support OpenGL 1.x the 3D view is replaced with an information window. An example of this information window is shown in illustration 2.

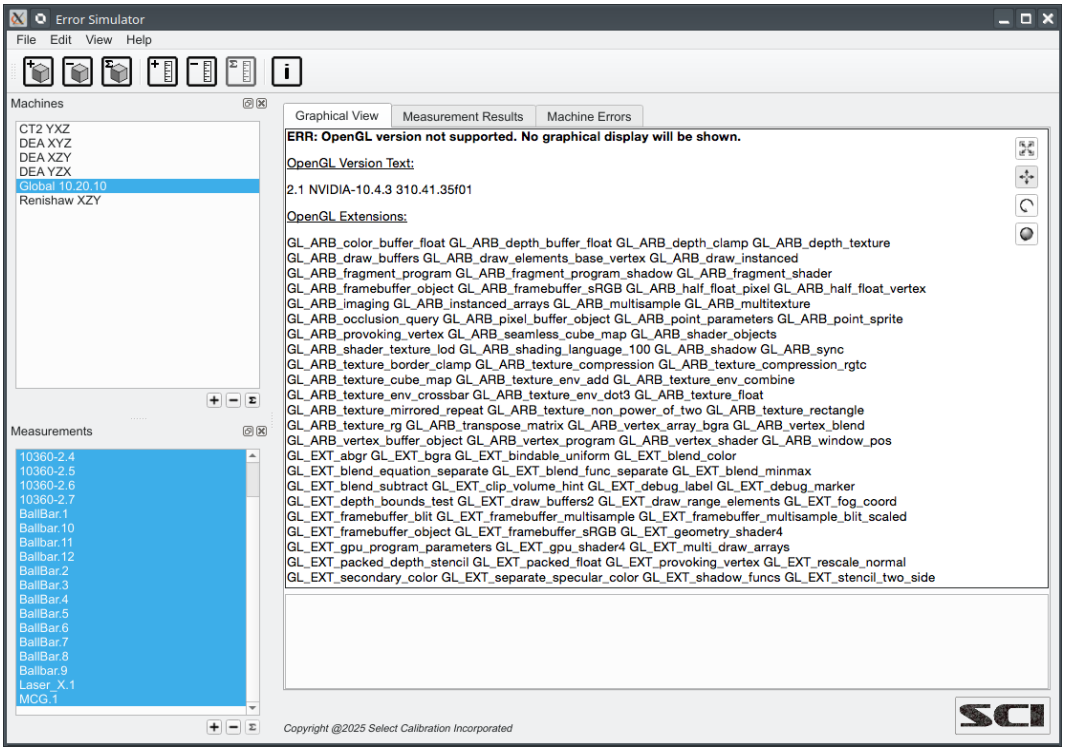



*Illustration 2: Information screen that is displayed with unsupported OpenGL versions.*

## Machines

A machine is a configuration of the simulated CMM with unique dimensions, kinematic order, parameter errors, and other characteristics. Machines can be added using the *Add Machine* option from the toolbar or from the edit functions below the list of machines. Selected machines can be removed using the *Remove Machine* option from the toolbar or from the edit functions below the list of machines. Existing machines can be modified using the edit functions below the machine list or from the main toolbar of the *Error Simulator* utility.

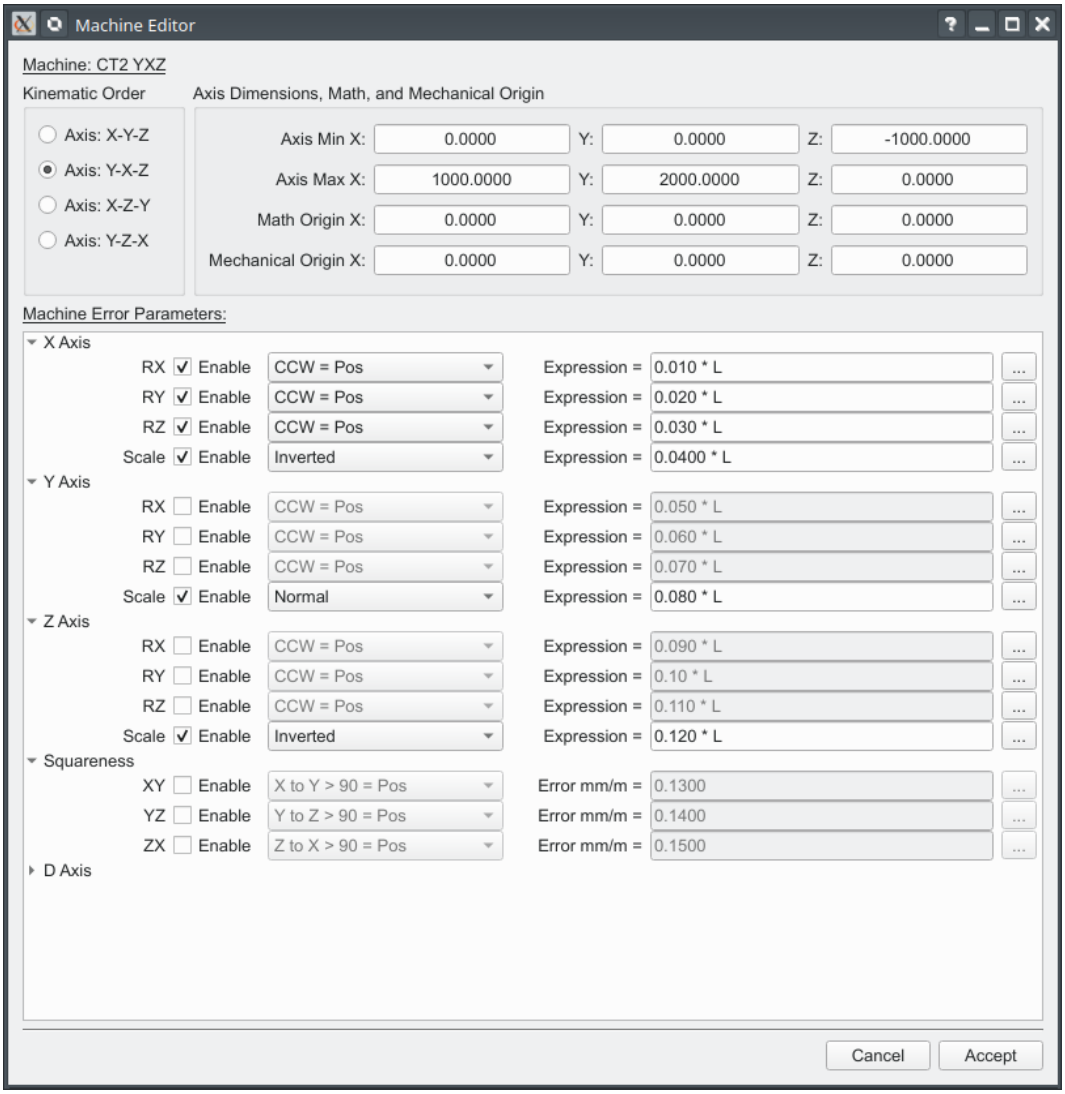



*Illustration 3: View of the Machine editor of the Error Simulator utility.*

## Kinematic Order

The kinematic order defines how the axis of a machine is connected to each other. There are four kinematic orders supported by the *Error Simulator* utility.

*Table 2: Kinematic Order Options:*

| *Kinematic Order* | *Description* |
|---|---|
| X-Y-Z | The axis of the simulated CMM has the X as the first axis, the Y connected to the X, and the Z connected to the Y. This configuration is assumed to be a vertical arm CMM. This configuration is typical for legacy DEA and LK machines. |
| Y-X-Z | The axis of the simulated CMM has the Y as the first axis, the X connected to the Y, and the Z connected to the X. This configuration is assumed to be a vertical arm CMM. This configuration is the common configuration used for |

| *Kinematic Order* | *Description* |
|---|---|
| | bridge or gantry CMM's. |
| X-Z-Y | The axis of the simulated CMM has the X as the first axis, the Z connected to the X, and the Y connected to the Z. This configuration is assumed to be a horizontal arm CMM. |
| Y-Z-X | The axis of the simulated CMM has the Y as the first axis, the Z connected to the Y, and the X connected to the Z. This configuration is assumed to be a horizontal arm CMM. |

## Machine Axis Setup

The machine axis setup defines the limits of the machine axis, the mechanical origin, and the compensation correction math origin. The math origin defines the position where calculations of errors from the machine angular compensation data is performed. The mechanical origin defines the position where the physical rotation occurs on a machine. The mechanical rotation is critical for proper calculation of deflection effects for a horizontal arm CMM and can have an impact on straightness data for any configuration of CMM.

Illustration 4 shows an example of the mechanical rotation point on the bridge axis of a CMM and how it impacts the horizontal straightness of the related axis. The impact of the mechanical rotation point can have a significant impact on the type of data needed to correct for the known errors.

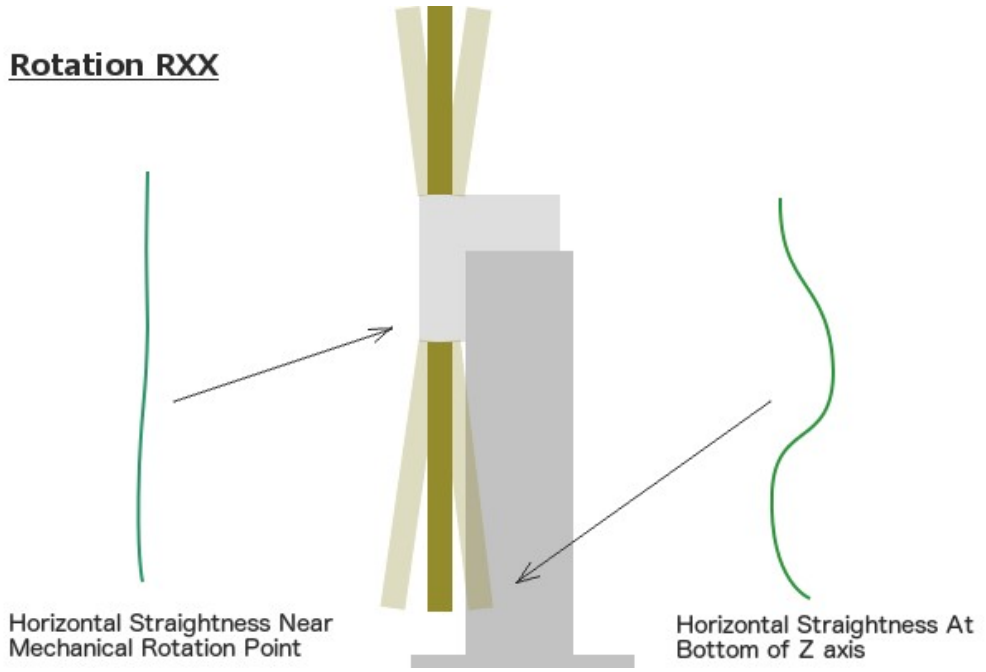



*Illustration 4: Example of the effect of rotation error RXX at different points in the X axis affecting the Y axis straightness.*

## Expression Variables

The following are variables that can be used for the machine error expressions:

*Table 3: Expression Variables:*

| *Variable* | *Description* |
|---|---|
| L | Position in the map coordinates specific for each axis. The value is from the XYZ zero point regardless if this position is inside the machine volume or not. |

## Machine Error Parameters

The X, Y, and Z machine axis can have up to four modifiable error parameters. For horizontal arm CMM's an additional D axis is available allowing the entry of a value representing the tower deflection angle. The variables that can be modified are the scale and three angular parameters. The straightness parameters cannot be directly changed and are calculated automatically based on the corresponding angular data.

All parameters are entered as either a constant or expression using the variable 'L' except for deflection and squareness which are assumed to be a length dependent values.

*Table 4: Axis Expression Examples:*

| *Expression* | *Description* |
|---|---|
| $0.005$ | This value will be applied evenly to all parameter data of the simulated CMM. |
| $0.005 * L$ | The parameter data is a gradient with variable *L* substituted for the actual position of the axis. |
| $0.005 + 0.002 * L + 0.003 * L^2 - 0.004 * L^3$ | The parameter data is in the form of a polynomial with coefficients with variable *L* substituted for the actual position of the axis. The resulting shape from this expression is complex. |

*Table 5: Squareness Expression Example:*

| *Expression* | *Description* |
|---|---|
| $0.005$ | This value represents a deviation from the true square of an axis. The input value is the deviation at a length of 1m. |

## Expression Editor

The expression editor allows the entry of errors along the length of the machine axis that will be converted into an equivalent expression for the selected axis parameter. This function is useful for errors that have an odd shape where it is easier to describe the desired end result. The expression editor dialog can be accessed by clicking on the ellipse button to the right of the expression field.

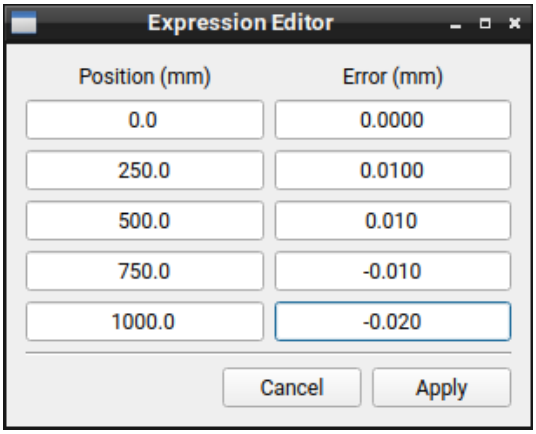



*Illustration 5: Expression editor showing five data points along the axis of the machine and the amount of desired error at each point.*

Using the inputs from the example shown in illustration 5 the resulting expression is:

$$0.0067*L+0.2933*L^2-0.7467*L^3+0.4267*L^4$$

*The expression editor is not available for squareness or deflection parameters. The entry for these fields is a constant representing the angle in mm/m.*

## Deflection Expressions

The tower deflection of a horizontal arm is entered as a constant value representing the rotation angle of the tower when measured with the Z at the top of the axis on a physical CMM. The angle units are mm/m.

Deflection errors is based on the expected change in the tower angle as the arm axis moves from one extreme to the other combined with the distance from the mechanical rotational center. Most software apply compensation from the machine zero but the reality is that the weight of the arm rotates the tower outward at the home position and does the opposite when the arm is fully extended with only the arm at mid position resulting in zero deflection. The simulation of the deflection matches the expected deflection as shown in illustration 6 and not that of the typical software correction.

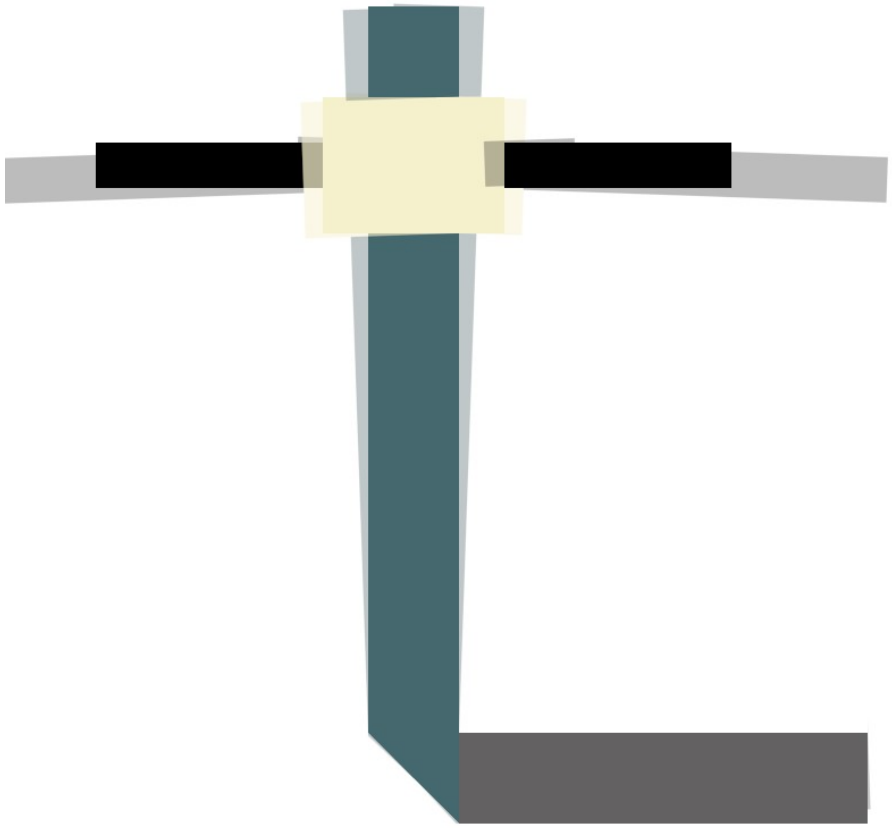


*Illustration 6: Deflection estimation.*

*For horizontal arm CMM's it is important the mechanical rotation point is set appropriately.*

*When viewing the error map data for the machine the tower deflection will be shown as a table containing the result of the expression at different points along the two input axis.*

## Angular Expression Signs

For angular data the interpretation of the machine error expression is determined by the sign selection of *CCW=Pos* or *CW=Pos* when viewing from the positive end of the rotation axis. This selection does not change the sign of the generated map data but how the data will be interpreted. *CCW* and *CW* are short for *Counter Clock Wise* and *Clock Wise* with *Pos* a short form for positive. All angular signs are from the point of view of the positive view of the third axis.

*Most compensation error maps use the sign convention of CCW = Pos but not all. DEA maps, for example, use a mix of CCW = Pos and CW = Pos.*

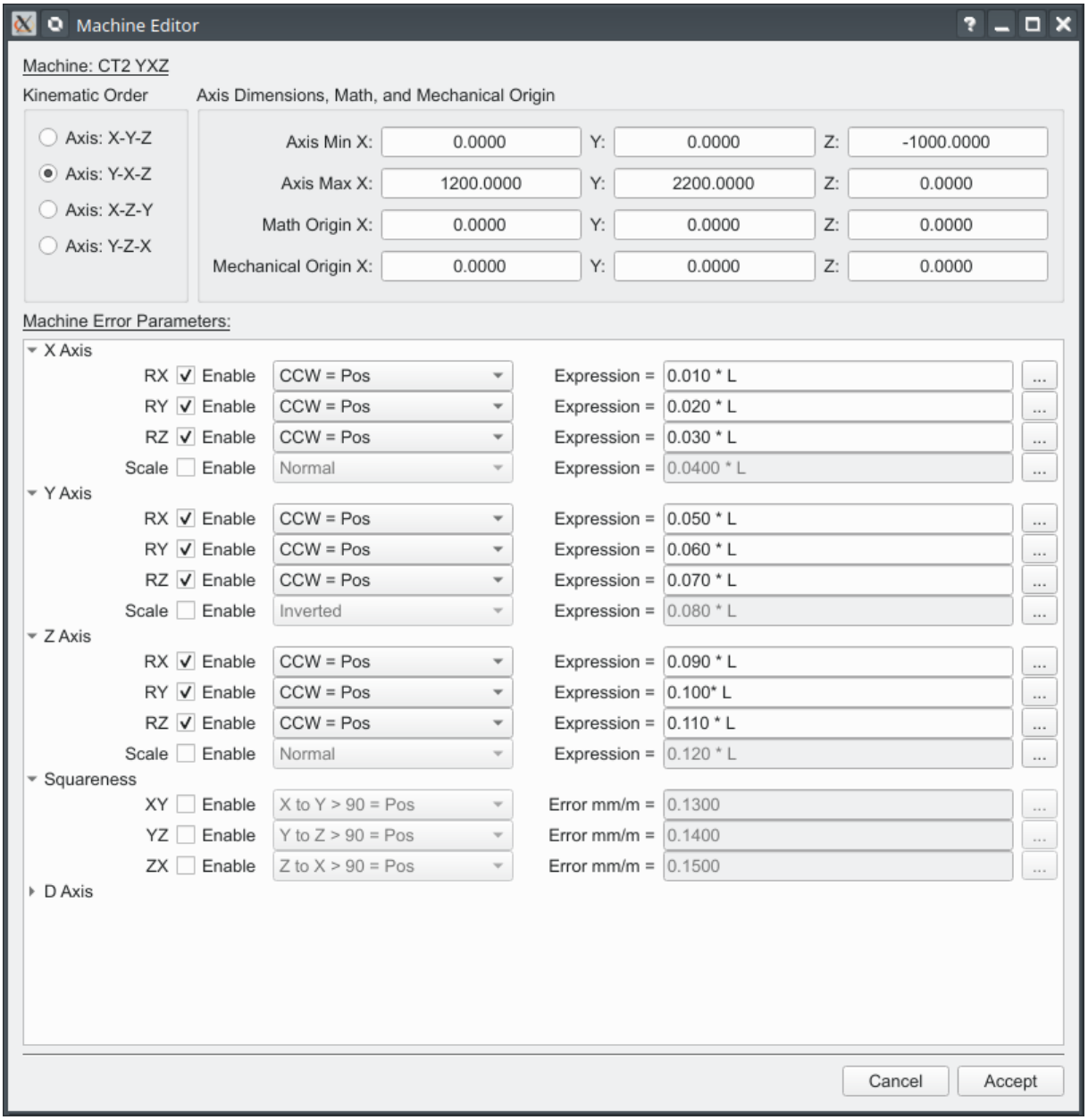



*Illustration 7: Defining angular parameters for testing. Sign is CCW = Pos for all entries.*

The simulated map data can be seen in the *Machine Errors* section of the data display. Using the entries from illustration 7 the following map data was created.

```
Selected Machine: CT2 YXZ

Squareness
------------------------------------------------------------------------------
YZ: 0.0000 mm/m
XY: 0.0000 mm/m
ZX: 0.0000 mm/m
```

X Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 200.0 | 0.0000 | -0.0018 | 0.0012 | 0.0020 | 0.0040 | 0.0060 |
| 400.0 | 0.0000 | -0.0024 | 0.0016 | 0.0040 | 0.0080 | 0.0120 |
| 600.0 | 0.0000 | -0.0019 | 0.0012 | 0.0060 | 0.0120 | 0.0180 |
| 800.0 | 0.0000 | -0.0001 | 0.0001 | 0.0080 | 0.0160 | 0.0240 |
| **1000.0** | 0.0000 | 0.0029 | -0.0019 | **0.0100** | **0.0200** | **0.0300** |
| 1200.0 | 0.0000 | 0.0071 | -0.0047 | 0.0120 | 0.0240 | 0.0360 |

Y Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 200.0 | 0.0090 | 0.0000 | -0.0064 | 0.0100 | 0.0120 | 0.0140 |
| 400.0 | 0.0151 | 0.0000 | -0.0108 | 0.0200 | 0.0240 | 0.0280 |
| 600.0 | 0.0185 | 0.0000 | -0.0132 | 0.0300 | 0.0360 | 0.0420 |
| 800.0 | 0.0191 | 0.0000 | -0.0136 | 0.0400 | 0.0480 | 0.0560 |
| **1000.0** | 0.0168 | 0.0000 | -0.0120 | **0.0500** | **0.0600** | **0.0700** |
| 1200.0 | 0.0118 | 0.0000 | -0.0084 | 0.0600 | 0.0720 | 0.0840 |
| 1400.0 | 0.0040 | 0.0000 | -0.0028 | 0.0700 | 0.0840 | 0.0980 |
| 1600.0 | -0.0067 | 0.0000 | 0.0048 | 0.0800 | 0.0960 | 0.1120 |
| 1800.0 | -0.0201 | 0.0000 | 0.0143 | 0.0900 | 0.1080 | 0.1260 |
| 2000.0 | -0.0363 | 0.0000 | 0.0259 | 0.1000 | 0.1200 | 0.1400 |
| 2200.0 | -0.0553 | 0.0000 | 0.0395 | 0.1100 | 0.1320 | 0.1540 |

Z Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| -200.0 | -0.0047 | 0.0043 | 0.0000 | -0.0180 | -0.0200 | -0.0220 |
| -400.0 | -0.0055 | 0.0049 | 0.0000 | -0.0360 | -0.0400 | -0.0440 |
| -600.0 | -0.0022 | 0.0020 | 0.0000 | -0.0540 | -0.0600 | -0.0660 |
| -800.0 | 0.0051 | -0.0046 | 0.0000 | -0.0720 | -0.0800 | -0.0880 |
| **-1000.0** | 0.0163 | -0.0147 | 0.0000 | **-0.0900** | **-0.1000** | **-0.1100** |

*The straightness parameters and signs are calculated automatically from the input angular data. These parameters cannot be directly modified.*

*Angular parameters may introduce an unintentional squareness error in the simulated CMM. Although it would be preferable to not have residual squareness errors from certain angular errors it is not avoidable.*

Using the *Error Simulator* utility a set of B89 ballbar positions shown in illustration 8 was created that would be impacted by the angular errors listed in illustration 7.

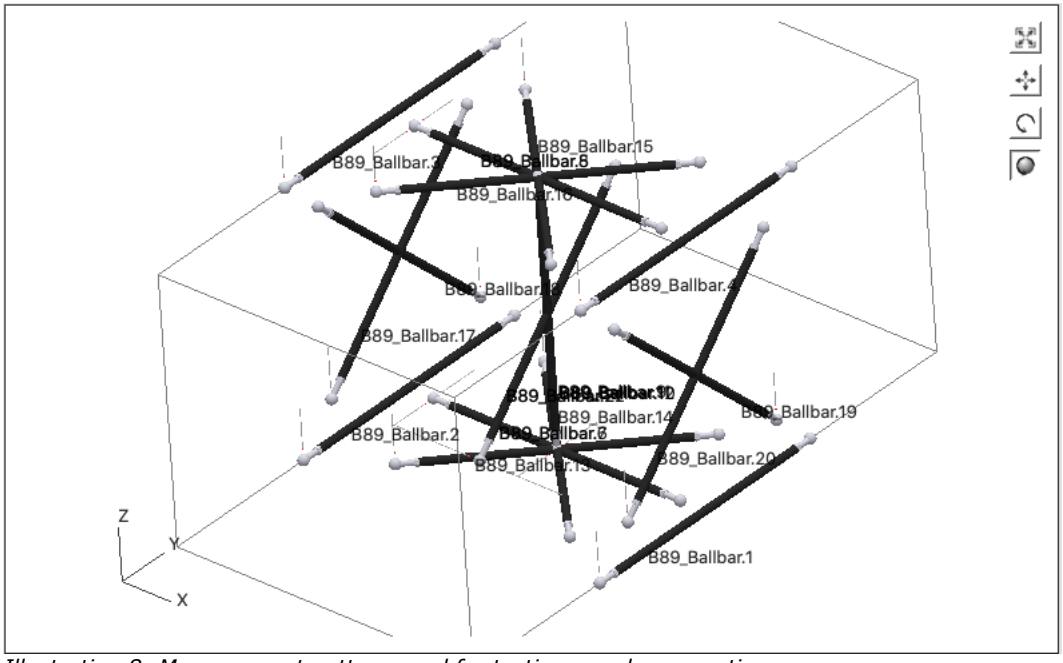



*Illustration 8: Measurement pattern used for testing angular corrections.*

Performing an evaluation test using a BnS CT2 compensation error map, which uses the sign convention of *CCW = Pos* for all axis angular data, the B89 ballbar data was externally processed and produced the following set of corrections necessary to remove the measurement errors described by the ballbar data:

CMM Configuration YXZ

| Pos | TXx | TXy | TXz | RXx | RXy | Rxz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 100.0 | 0.0 | 1.6 | -1.1 | -1.0 | -2.0 | -3.0 |
| 200.0 | 0.0 | 3.0 | -2.0 | -2.0 | -4.0 | -6.0 |
| 300.0 | 0.0 | 4.0 | -2.7 | -3.0 | -6.0 | -9.0 |
| 400.0 | 0.0 | 4.8 | -3.2 | -4.0 | -8.0 | -12.0 |
| 500.0 | 0.0 | 5.2 | -3.5 | -5.0 | -10.0 | -15.0 |
| 600.0 | 0.0 | 5.4 | -3.6 | -6.0 | -12.0 | -18.0 |
| 700.0 | 0.0 | 5.2 | -3.5 | -7.0 | -14.0 | -21.0 |
| 800.0 | 0.0 | 4.8 | -3.2 | -8.0 | -16.0 | -24.0 |
| 900.0 | 0.0 | 4.0 | -2.7 | -9.0 | -18.0 | -27.0 |
| **1000.0** | 0.0 | 3.0 | -2.0 | **-10.0** | **-20.0** | **-30.0** |
| 1100.0 | 0.0 | 1.6 | -1.1 | -11.0 | -22.0 | -33.0 |
| 1200.0 | 0.0 | 0.0 | -0.0 | -12.0 | -24.0 | -36.0 |

| Pos | TYx | TYy | TYz | RYx | RYy | RYz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 200.0 | -15.4 | 0.0 | 11.0 | -10.0 | -12.0 | -14.0 |
| 400.0 | -28.0 | 0.0 | 20.0 | -20.0 | -24.0 | -28.0 |
| 600.0 | -37.8 | 0.0 | 27.0 | -30.0 | -36.0 | -42.0 |
| 800.0 | -44.8 | 0.0 | 32.0 | -40.0 | -48.0 | -56.0 |
| **1000.0** | -49.0 | 0.0 | 35.0 | **-50.0** | **-60.0** | **-70.0** |
| 1200.0 | -50.4 | 0.0 | 36.0 | -60.0 | -72.0 | -84.0 |
| 1400.0 | -49.0 | 0.0 | 35.0 | -70.0 | -84.0 | -98.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1600.0 | -44.8 | 0.0 | 32.0 | -80.0 | -96.0 | -112.0 |
| 1800.0 | -37.8 | 0.0 | 27.0 | -90.0 | -108.0 | -126.0 |
| 2000.0 | -28.0 | 0.0 | 20.0 | -99.9 | -120.0 | -140.0 |
| 2200.0 | -15.4 | 0.0 | 11.0 | -109.9 | -132.0 | -154.0 |
| 2400.0 | -0.0 | 0.0 | 0.0 | -119.9 | -144.0 | -168.0 |

| Pos | TZx | TZy | TZz | RZx | RZy | RZz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| -100.0 | 5.5 | -5.0 | 0.0 | 9.0 | 10.0 | 11.0 |
| -200.0 | 10.0 | -9.0 | 0.0 | 18.0 | 20.0 | 22.0 |
| -300.0 | 13.5 | -12.2 | 0.0 | 27.0 | 30.0 | 33.0 |
| -400.0 | 16.0 | -14.4 | 0.0 | 36.0 | 40.0 | 44.0 |
| -500.0 | 17.5 | -15.8 | 0.0 | 45.0 | 50.0 | 55.0 |
| -600.0 | 18.0 | -16.2 | 0.0 | 54.0 | 60.0 | 66.0 |
| -700.0 | 17.5 | -15.8 | 0.0 | 63.0 | 70.0 | 77.0 |
| -800.0 | 16.0 | -14.4 | 0.0 | 72.0 | 80.0 | 88.0 |
| -900.0 | 13.5 | -12.2 | 0.0 | 81.0 | 90.0 | 99.0 |
| **-1000.0** | 10.0 | -9.0 | 0.0 | **90.0** | **100.0** | **110.0** |
| -1100.0 | 5.5 | -5.0 | 0.0 | 99.0 | 110.0 | 121.0 |
| -1200.0 | 0.0 | -0.0 | 0.0 | 108.0 | 120.0 | 132.0 |

*All axis from this example data have a negative correction gradient as all errors were all created with a positive gradient. Negative axis positions will show a reversed sign correction as a result.*

## Scale Expression Signs

The scale data correction sign can be either *Normal* or *Inverted*. Normal corrections are based on the idea of measuring a physical artifact such as a step gauge or gauge block and then adding the deviations directly to the compensation error map for removal. Inverted means that the deviations found from the artifact measurement must be sign-flipped in order to remove the measured error.

*The Error Simulator utility treats all measurements as artifacts including B89 Laser and 10360-2 Laser. The scale signs for any laser measurements should be inverted as a result. A future version of the Error Simulator may address this limitation.*

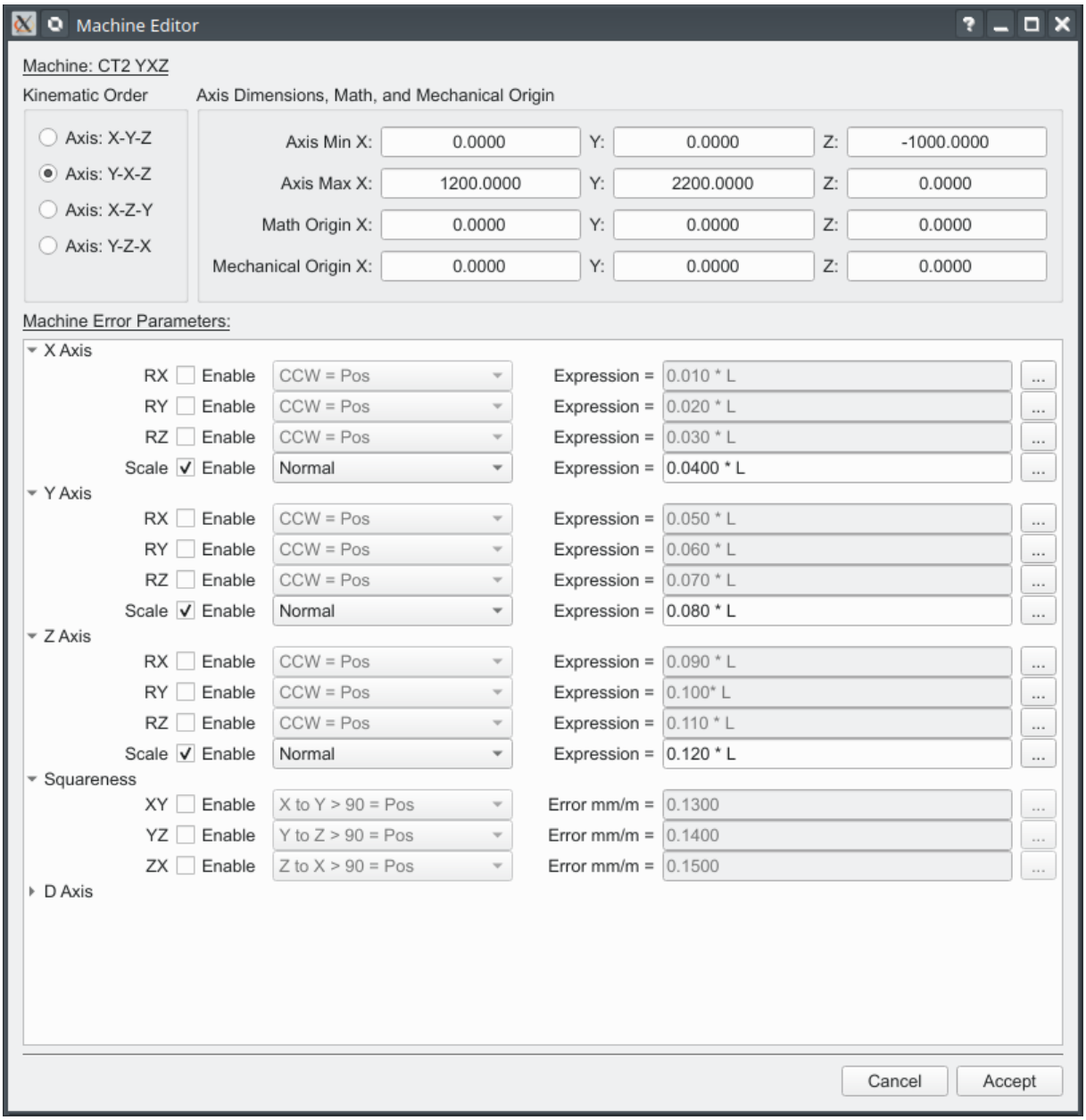



*Illustration 9: Defining scale parameters for testing. Sign is set to Normal for all scale entries.*

Using the entries from illustration 9 the following map data is created.

```
Selected Machine: CT2 YXZ

Squareness
--------------------------------------------------------------------------------
YZ: 0.0000 mm/m
XY: 0.0000 mm/m
ZX: 0.0000 mm/m
```

X Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 200.0 | 0.0080 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 400.0 | 0.0160 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 600.0 | 0.0240 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 800.0 | 0.0320 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| **1000.0** | **0.0400** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1200.0 | 0.0480 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Y Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 200.0 | 0.0000 | 0.0160 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 400.0 | 0.0000 | 0.0320 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 600.0 | 0.0000 | 0.0480 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 800.0 | 0.0000 | 0.0640 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| **1000.0** | 0.0000 | **0.0800** | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1200.0 | 0.0000 | 0.0960 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1400.0 | 0.0000 | 0.1120 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1600.0 | 0.0000 | 0.1280 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1800.0 | 0.0000 | 0.1440 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2000.0 | 0.0000 | 0.1600 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2200.0 | 0.0000 | 0.1760 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Z Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| -200.0 | 0.0000 | 0.0000 | -0.0240 | 0.0000 | 0.0000 | 0.0000 |
| -400.0 | 0.0000 | 0.0000 | -0.0480 | 0.0000 | 0.0000 | 0.0000 |
| -600.0 | 0.0000 | 0.0000 | -0.0720 | 0.0000 | 0.0000 | 0.0000 |
| -800.0 | 0.0000 | 0.0000 | -0.0960 | 0.0000 | 0.0000 | 0.0000 |
| **-1000.0** | 0.0000 | 0.0000 | **-0.1200** | 0.0000 | 0.0000 | 0.0000 |

The measurement pattern created with the error simulator is a set of ballbar positions along each axis of the simulated CMM as shown in illustration 10.

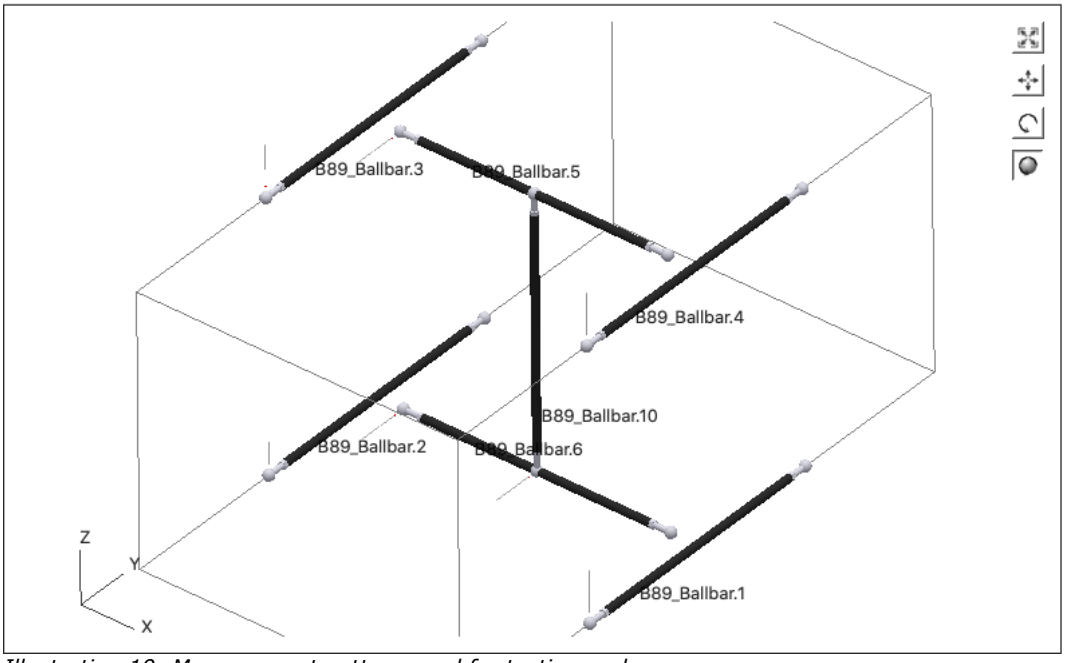



*Illustration 10: Measurement pattern used for testing scale errors.*

Using a BnS CT2 compensation error map, which is known to use the normal sign convention for scale data, the simulated ballbar measurements were processed and produced the following set of corrections:

CMM Configuration YXZ

| Pos | TXx | TXy | TXz | RXx | RXy | Rxz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 100.0 | -4.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 200.0 | -8.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 300.0 | -12.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 400.0 | -16.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 500.0 | -20.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 600.0 | -24.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700.0 | -28.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 800.0 | -32.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 900.0 | -36.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **1000.0** | **-40.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1100.0 | -44.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1200.0 | -48.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Pos | TYx | TYy | TYz | RYx | RYy | RYz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 200.0 | 0.0 | -16.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 400.0 | 0.0 | -32.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 600.0 | 0.0 | -48.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 800.0 | 0.0 | -64.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **1000.0** | 0.0 | **-80.0** | 0.0 | 0.0 | 0.0 | 0.0 |
| 1200.0 | 0.0 | -96.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1400.0 | 0.0 | -112.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1600.0 | 0.0 | -128.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1800.0 | 0.0 | -144.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2000.0 | 0.0 | -160.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2200.0 | 0.0 | -176.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2400.0 | 0.0 | -192.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Pos | TZx | TZy | TZz | RZx | RZy | RZz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| -100.0 | 0.0 | 0.0 | 12.0 | 0.0 | 0.0 | 0.0 |
| -200.0 | 0.0 | 0.0 | 24.0 | 0.0 | 0.0 | 0.0 |
| -300.0 | 0.0 | 0.0 | 36.0 | 0.0 | 0.0 | 0.0 |
| -400.0 | 0.0 | 0.0 | 48.0 | 0.0 | 0.0 | 0.0 |
| -500.0 | 0.0 | 0.0 | 60.0 | 0.0 | 0.0 | 0.0 |
| -600.0 | 0.0 | 0.0 | 72.0 | 0.0 | 0.0 | 0.0 |
| -700.0 | 0.0 | 0.0 | 84.0 | 0.0 | 0.0 | 0.0 |
| -800.0 | 0.0 | 0.0 | 96.0 | 0.0 | 0.0 | 0.0 |
| -900.0 | 0.0 | 0.0 | 108.0 | 0.0 | 0.0 | 0.0 |
| **-1000.0** | 0.0 | 0.0 | **120.0** | 0.0 | 0.0 | 0.0 |
| -1100.0 | 0.0 | 0.0 | 132.0 | 0.0 | 0.0 | 0.0 |
| -1200.0 | 0.0 | 0.0 | 144.0 | 0.0 | 0.0 | 0.0 |

## Squareness Signs

For squareness the interpretation is determined by the sign selection of 'A *to B > 90 = Pos*' or 'A *to B < 90 = Pos*' where A and B represent the two axis of interest. The idea is that between any two axis the angle between them will be greater than 90 degrees, less than 90 degrees, or exactly 90 degrees.

*Sign convention for squareness is quite varied between manufacturers and no rules appear to exist. The method used by BnS appears to be the most logical and was adopted for this utility.*

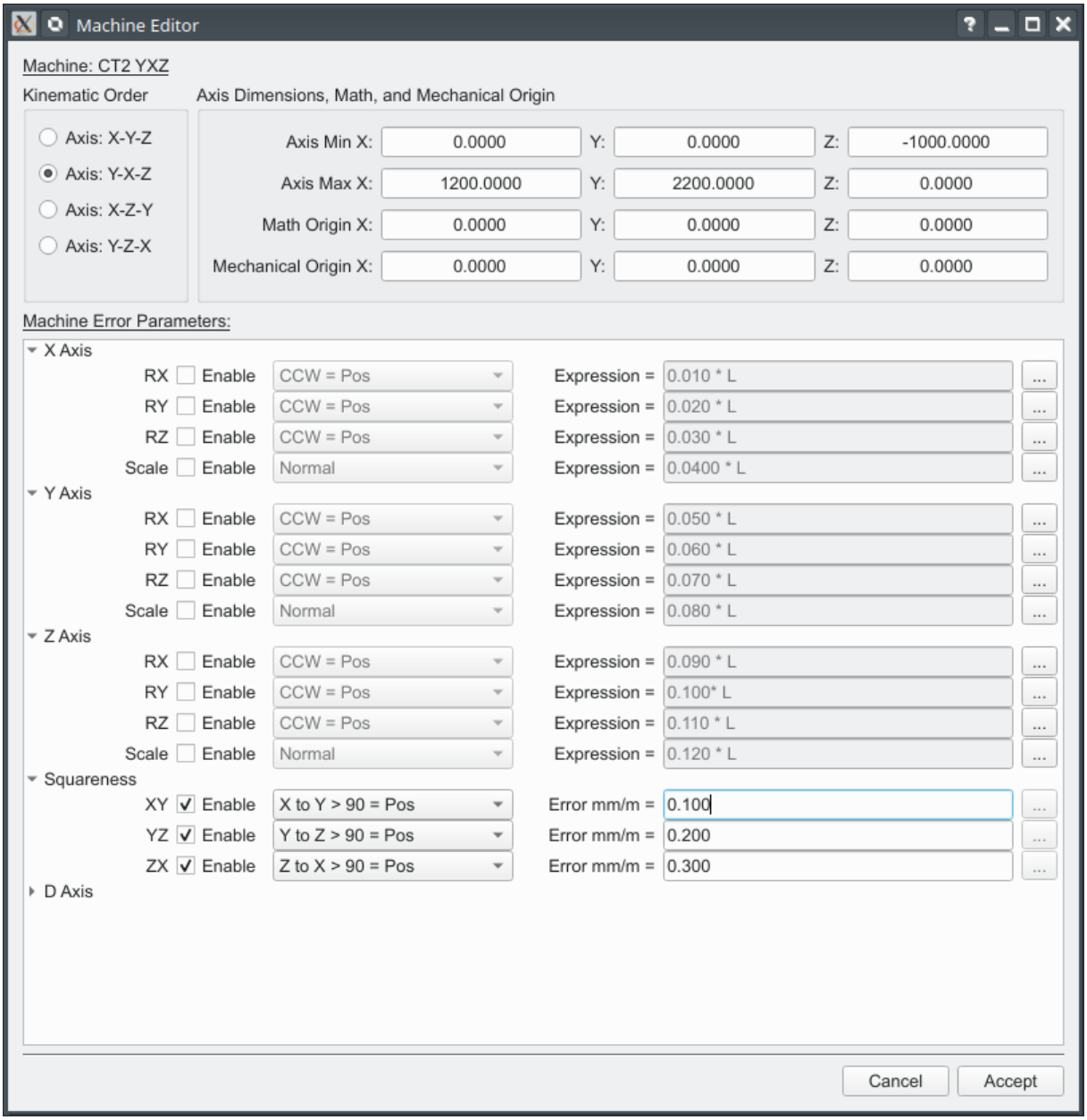



*Illustration 11: Defining angular parameters for testing. Sign is CCW = Pos for all entries.*

Using the entries from illustration 11 the following map data was created.

```
Selected Machine: CT2 YXZ

Squareness
--------------------------------------------------------------------------------
YZ: 0.2000 mm/m
XY: 0.1000 mm/m
ZX: 0.3000 mm/m

X Axis Data.  Linear units are mm, angular units are mm/m.
--------------------------------------------------------------------------------
```

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 200.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 400.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 600.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 800.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1000.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1200.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Y Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 200.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 400.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 600.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 800.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1000.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1200.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1400.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1600.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 1800.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2000.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 2200.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Z Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| -200.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| -400.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| -600.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| -800.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| -1000.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

The measurement pattern created with the *Error Simulator* is shown in illustration 12 consisting of a set of B89 ballbar positions that are able to detect squareness errors.

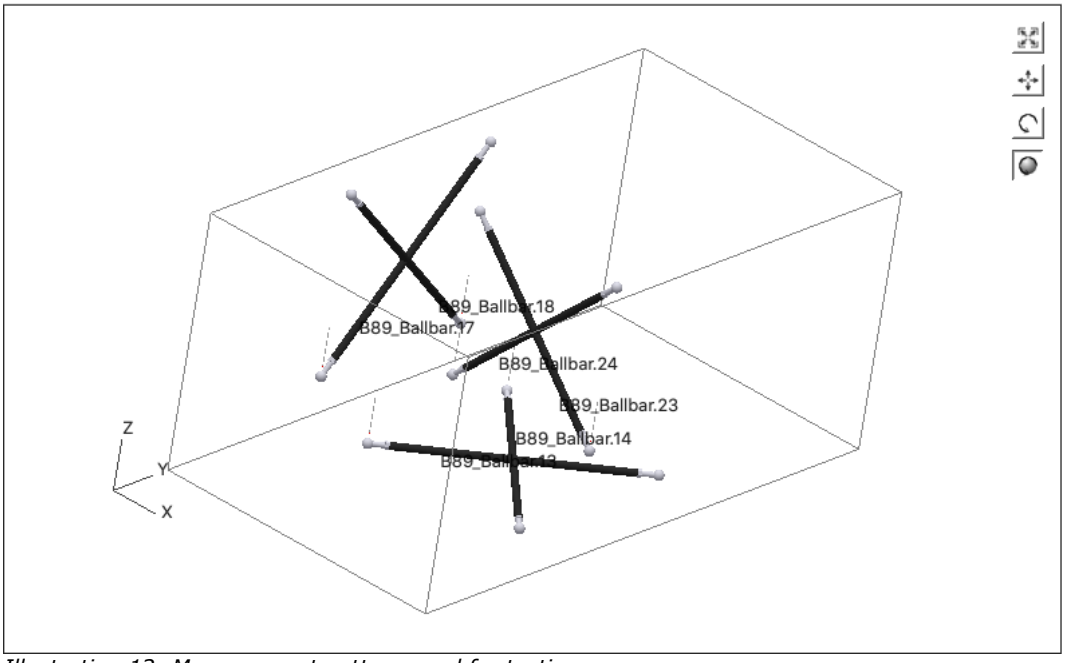



*Illustration 12: Measurement pattern used for testing squareness errors.*

Using a BnS CT2 compensation error map the B89 ballbar data was processed and produced the following set of corrections:

CMM Configuration YXZ

| Pos | TXx | TXy | TXz | RXx | RXy | Rxz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 200.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 300.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 400.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 500.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 600.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 700.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 800.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 900.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1000.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1200.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| Pos | TYx | TYy | TYz | RYx | RYy | RYz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 200.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 400.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 600.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 800.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1000.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1200.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1400.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1600.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1800.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

```
   2000.0     0.0     0.0     0.0     0.0     0.0     0.0
   2200.0     0.0     0.0     0.0     0.0     0.0     0.0
   2400.0     0.0     0.0     0.0     0.0     0.0     0.0

      Pos     TZx     TZy     TZz     RZx     RZy     RZz
-------------------------------------------------------------
      0.0     0.0     0.0     0.0     0.0     0.0     0.0
   -100.0     0.0     0.0     0.0     0.0     0.0     0.0
   -200.0     0.0     0.0     0.0     0.0     0.0     0.0
   -300.0     0.0     0.0     0.0     0.0     0.0     0.0
   -400.0     0.0     0.0     0.0     0.0     0.0     0.0
   -500.0     0.0     0.0     0.0     0.0     0.0     0.0
   -600.0     0.0     0.0     0.0     0.0     0.0     0.0
   -700.0     0.0     0.0     0.0     0.0     0.0     0.0
   -800.0     0.0     0.0     0.0     0.0     0.0     0.0
   -900.0     0.0     0.0     0.0     0.0     0.0     0.0
  -1000.0     0.0     0.0     0.0     0.0     0.0     0.0
  -1100.0     0.0     0.0     0.0     0.0     0.0     0.0
  -1200.0     0.0     0.0     0.0     0.0     0.0     0.0

Quad XY: -100.0  Quad YZ: -200.0  Quad ZX: -300.0
```

## Measurements

The measurement section allows creation, selection, editing, or deletion of measurements that are to be evaluated from with the selected machine. Five different kinds of measurements are currently supported by the *Error Simulator* utility:

*Table 6: Measurement Types:*

| *Measurement Type* | *Description* |
|---|---|
| B89 Ballbar | Results from ASME B89.4.1 ballbar positions placed anywhere in the machine volume. The output is a single file containing all measured ballbar positions. |
| B89 Laser | Measurement using a six parameter laser based on the ASME B89.4.1 LDA test. If the measurement axis is close to one of the three machine axis the results will show all linear and angular data otherwise only linear data is shown. The output is a pair of files for each measurement position (one for the laser and one for the machine). |
| 10360 Ballbar | Measurement of five unique lengths performed along any measurement line of the CMM as defined by 10360-2 using a six sphere ballbar. The output is a single file for each measurement position. |
| 10360 Laser | Measurement of five unique lengths performed along any measurement line of the CMM as defined by 10360-2. The output is a pair of files for each measurement position (one for the laser and one for the machine). |
| Machine Checking Gauge | Results from the Renishaw MCG. The output is a single file containing |

| *Measurement Type* | *Description* |
|---|---|
| | all measured gauge points. |

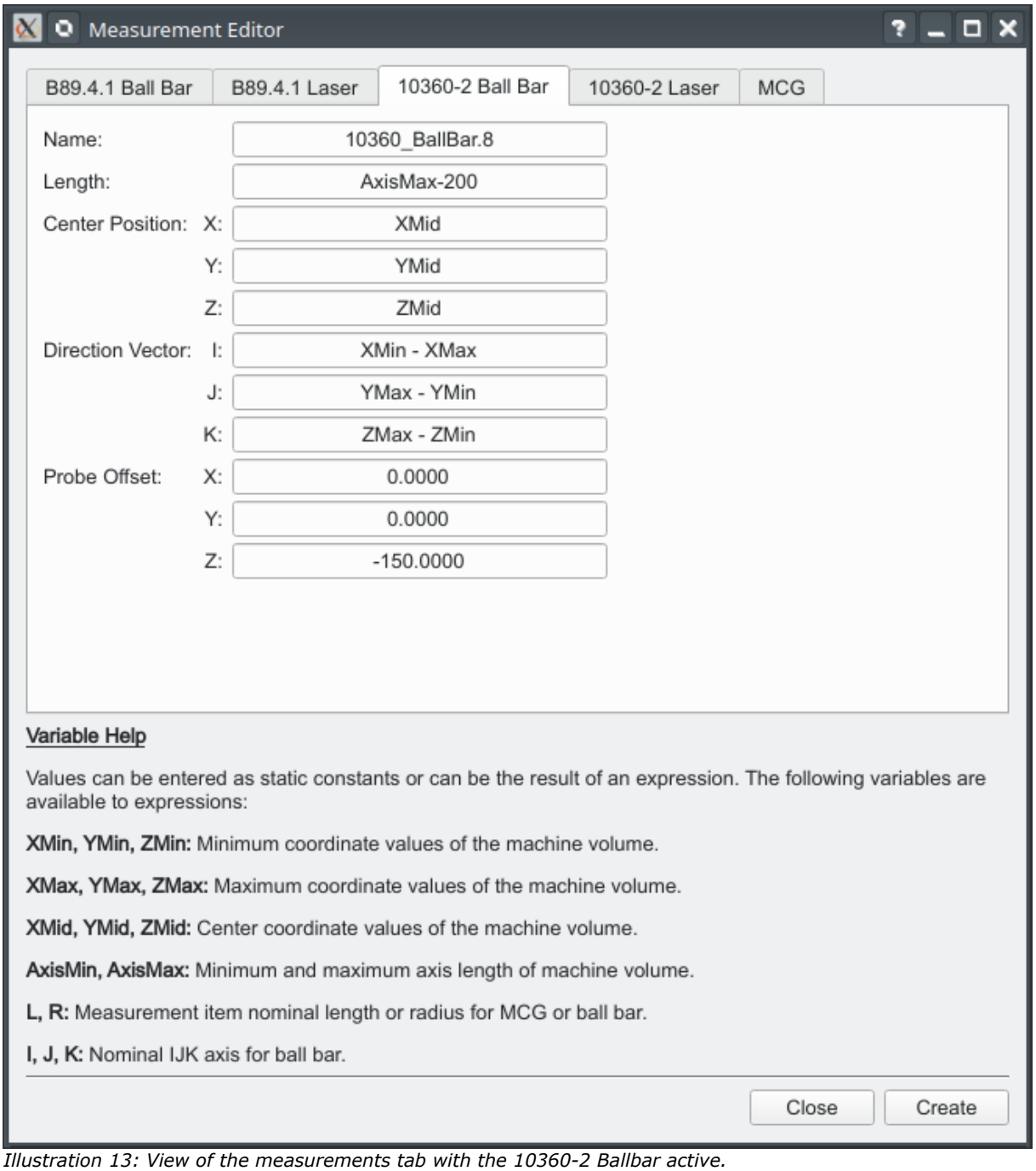



*Illustration 13: View of the measurements tab with the 10360-2 Ballbar active.*

## Managing Measurements

New measurements can be created by pressing the add button at the bottom of the measurement list or by clicking the add measurement toolbar option. When an existing measurement is selected prior to creating a new measurement the exiting item parameters are copied to the new measurement of the selected type. New measurements can be one of the five supported types and must be the active view when pressing create. The dialog will remain open until Close is clicked allowing more than one measurement, of any type, to be created. Selected measurements can be deleted using the remove measurement toolbar option or by pressing the remove button at the bottom of the measurement list. Selected measurements can be modified using the edit function from the toolbar of from the options at the bottom of the measurement list.

## Expression Variables.

The following are variables that can be used for measurement expressions:

*Table 7: Expression variables:*

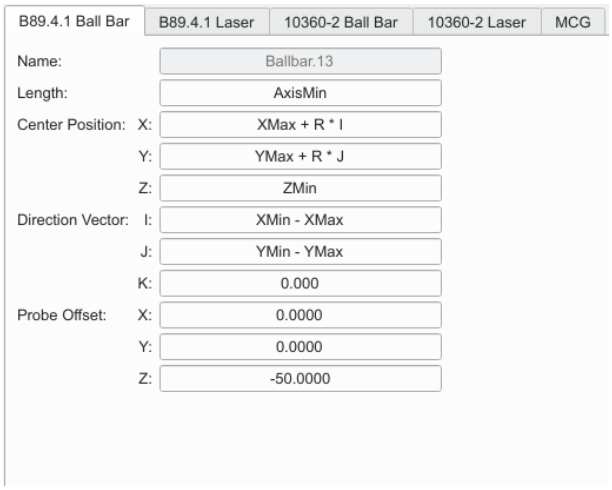
| *Variable* | *Description* |
|---|---|
| XMin | The minimum X axis machine coordinate. |
| YMin | The minimum Y axis machine coordinate. |
| ZMin | The minimum Z axis machine coordinate. |
| XMax | The maximum X axis machine coordinate. |
| YMax | The maximum Y axis machine coordinate. |
| ZMax | The maximum Z axis machine coordinate. |
| XMid | The center position of the X axis. |
| YMid | The center position of the Y axis. |
| ZMid | The center position of the Z axis. |
| AxisMin | The shortest length of the X, Y, or Z axis. |
| AxisMax | The longest length of the X, Y, or Z axis. |
| L | The nominal measurement length. |
| R | The nominal measurement length divided by two (L/2). |
| I | The normalized I value of the IJK direction. |
| J | The normalized J value of the IJK direction. |
| K | The normalized K value of the IJK direction. |

Some variables cannot be used in fields that result in the creation of the variable (variables used recursively). For example, the variable 'L' cannot be used inside any length field as the value of this variable must be determined by solving the expression of this field first.

## Measurement Variable Example

The following shows an example of a measurement expression for a ballbar. The table following the image describes the different variables used.

In this example the goal was to have a ballbar placed at the bottom of the machines Z axis in a direction between the back/left and front/right corners. Since the dimensions of the machine are not (or may not) be cubical the I and J values should not be assumed to be 0.707107 and 0.707107. Also, the position of one of the two spheres must be located at the back/left corner of the machines measurement volume. The length of the ballbar cannot be longer than the shortest machine axis.



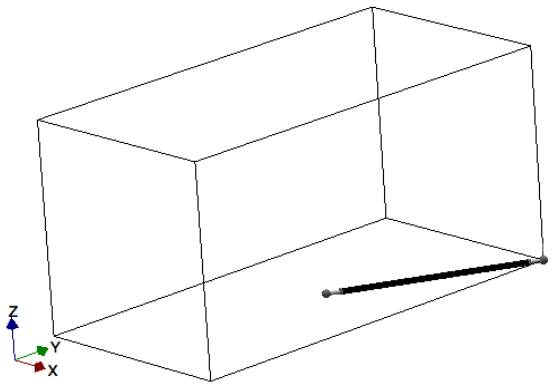




*Illustration 14: Image showing position of the ball bar based on expression parameters shown to the left.*

*Table 8: Measurement Example Value Entries:*

| *Expression Description* | *Description* |
|---|---|
| Name | The name of the measurement as it will appear in the measurement list. |
| Length | The variable *AxisMin* is used for the expression. The length of the ballbar will be the shortest axis of the machine. |
| Center Position X | The expression *XMax + R * I* will place the center of the ballbar measurement one half the length of the ballbar starting at the maximum X axis position and traveling in the normalized I value of the IJK direction. |
| Center Position Y | The expression Y*Max + R * J* will place the center of the ballbar measurement one half the length of the ballbar starting at the maximum Y axis position and traveling in the normalized J value of the IJK direction. |
| Center Position Z | The expression *ZMin* will place the center of the ballbar measurement at the lowest position in the Z axis. |
| Direction Vector I | The expression *XMin - XMax* defines the I value of the IJK direction. The direction is normalized automatically when processed. |
| Direction Vector J | The expression Y*Min - YMax* defines the J value of the IJK direction. The direction is normalized automatically when processed. |
| Direction Vector K | The expression *0* sets K value of the IJK direction to zero. |

| *Expression Description* | *Description* |
|---|---|
| Probe Offset X | The probe offset in the X axis direction used for the measurement. The value is entered as a constant. |
| Probe Offset Y | The probe offset in the Y axis direction used for the measurement. The value is entered as a constant. |
| Probe Offset Z | The probe offset in the Z axis direction used for the measurement. The value is entered as a constant. |

### Probe Offset Sign

The sign for the probe offset is always interpreted as the relative position of the stylus ruby from the probe connection point at the end of the last axis of the machine. The signs for all axis uses the standard sign convention and is reversed as compared to some inspection software (PC-DMIS for example).

*All measurements draw a simulated stylus provided the probe offset is not set to zero.*

### B89 Laser Measurements

All B89 laser measurements report scale, straightness, and all angular data typical for a six parameter laser. All B89 laser data is bidirectional.

*Measurement lines that are not parallel to an axis will only show scale errors. The straightness and angular fields will still exist but all values will be reported as zero.*

## Measurement Results

The measurement results shows the text result of all selected measurements. Depending on the type of data some measurements are combined into a single table such as the B89 ballbar data. Measurements that consist of more than one measured value are reported as a group for each selected measurement.

The following shows examples of measurement data displayed in this view:

```
MCG Measurement
-------------------------------------------------------------------------------
Name:            MCG.1
Probe Offset:    0.0000, 0.0000, -75.0000
Center Position: 500.0000, 1000.0000, -675.0000

  Elevation   Azimuth     Length     Error
-------------------------------------------------------------------------------
  -45.0616     0.0492   499.9626    -0.0374
  -45.0608    45.1014   500.0875     0.0875
  -45.0128    90.1248   500.1377     0.1377
  -44.9573   135.0971   500.1073     0.1073
  -44.9384   180.0434   500.0376     0.0376
  -44.9556   225.0040   499.9460    -0.0540
  -44.9871   269.9931   499.8626    -0.1374
  -45.0262   315.0081   499.8598    -0.1402
   -0.0573     0.0443   500.0001     0.0001
   -0.0751    45.0415   500.0246     0.0246
   -0.0286    90.0387   500.0002     0.0002
    0.0346   135.0415   499.9758    -0.0242
```

```
     0.0573   180.0443   500.0001     0.0001
     0.0464   225.0415   500.0245     0.0245
     0.0286   270.0387   500.0002     0.0002
    -0.0060   315.0415   499.9758    -0.0242
    44.9384     0.0393   500.0376     0.0376
    44.9363    44.9818   499.9371    -0.0629
    44.9871    89.9526   499.8626    -0.1374
    45.0455   134.9857   499.8686    -0.1314
    45.0616   180.0452   499.9626    -0.0374
    45.0416   225.0790   500.0786     0.0786
    45.0128   270.0843   500.1376     0.1376
    44.9765   315.0748   500.1161     0.1161

 Max Length Error:  0.1377
 Min Length Error: -0.1402

 10360 Ballbar Measurement
 ------------------------------------------------------------------------------------------
 Name:           10360_BallBar.1
 Probe Offset:   0.0000, 0.0000, -150.0000
 Start Position: 867.4235, 265.1531, -1017.4235
 Test Axis:      -0.408248290, 0.816496581, 0.408248290

    Nominal     Actual      Dev
 ------------------------------------------------------------------------------------------
     0.0000     0.0000     0.0000
   360.0000   359.9036    -0.0964
   720.0000   719.8108    -0.1892
  1080.0000  1079.7215    -0.2785
  1440.0000  1439.6357    -0.3643
  1800.0000  1799.5533    -0.4467

 Max Error:  0.0000
 Min Error: -0.4467
```

*Table 9: Options:*

| *Option* | *Description* |
|---|---|
| Create Evaluation Report | Create a file containing an extensive comparative set of results from the selected measurements using all combinations of active machine errors. |
| Output Measurements | Create one or more measurement files containing data suitable for external testing from the selected measurements. |
| Save Text | Create an output text file of all the currently displayed results. |

## Machine Errors

This view shows the calculated errors of the active machine. The errors are displayed in the form of a typical CMM error map. An example of this data is shown below:

```
Selected Machine: CT2 YXZ

Squareness
-------------------------------------------------------------------------------
YZ: 0.5000 mm/m
```

XY: 0.7050 mm/m
ZX: 0.1500 mm/m

X Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100.0 | 0.0010 | -0.0009 | 0.0006 | 0.0100 | 0.0020 | 0.0030 |
| 200.0 | 0.0020 | -0.0014 | 0.0009 | 0.0200 | 0.0040 | 0.0060 |
| 300.0 | 0.0030 | -0.0017 | 0.0011 | 0.0300 | 0.0060 | 0.0090 |
| 400.0 | 0.0040 | -0.0016 | 0.0011 | 0.0400 | 0.0080 | 0.0120 |
| 500.0 | 0.0050 | -0.0013 | 0.0009 | 0.0500 | 0.0100 | 0.0150 |
| 600.0 | 0.0060 | -0.0007 | 0.0004 | 0.0600 | 0.0120 | 0.0180 |
| 700.0 | 0.0070 | 0.0003 | -0.0002 | 0.0700 | 0.0140 | 0.0210 |
| 800.0 | 0.0080 | 0.0015 | -0.0010 | 0.0800 | 0.0160 | 0.0240 |
| 900.0 | 0.0090 | 0.0031 | -0.0020 | 0.0900 | 0.0180 | 0.0270 |
| 1000.0 | 0.0100 | 0.0049 | -0.0033 | 0.1000 | 0.0200 | 0.0300 |

Y Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 100.0 | 0.0043 | 0.0000 | -0.0031 | 0.0050 | 0.1000 | 0.0070 |
| 200.0 | 0.0080 | 0.0000 | -0.0057 | 0.0100 | 0.2000 | 0.0140 |
| 300.0 | 0.0110 | 0.0000 | -0.0078 | 0.0150 | 0.3000 | 0.0210 |
| 400.0 | 0.0133 | 0.0000 | -0.0095 | 0.0200 | 0.4000 | 0.0280 |
| 500.0 | 0.0148 | 0.0000 | -0.0106 | 0.0250 | 0.5000 | 0.0350 |
| 600.0 | 0.0157 | 0.0000 | -0.0112 | 0.0300 | 0.6000 | 0.0420 |
| 700.0 | 0.0158 | 0.0000 | -0.0113 | 0.0350 | 0.7000 | 0.0490 |
| 800.0 | 0.0153 | 0.0000 | -0.0109 | 0.0400 | 0.8000 | 0.0560 |
| 900.0 | 0.0141 | 0.0000 | -0.0100 | 0.0450 | 0.9000 | 0.0630 |
| 1000.0 | 0.0121 | 0.0000 | -0.0087 | 0.0500 | 1.0000 | 0.0700 |
| 1100.0 | 0.0095 | 0.0000 | -0.0068 | 0.0550 | 1.1000 | 0.0770 |
| 1200.0 | 0.0062 | 0.0000 | -0.0044 | 0.0600 | 1.2000 | 0.0840 |
| 1300.0 | 0.0021 | 0.0000 | -0.0015 | 0.0650 | 1.3000 | 0.0910 |
| 1400.0 | -0.0026 | 0.0000 | 0.0019 | 0.0700 | 1.4000 | 0.0980 |
| 1500.0 | -0.0081 | 0.0000 | 0.0058 | 0.0750 | 1.5000 | 0.1050 |
| 1600.0 | -0.0142 | 0.0000 | 0.0101 | 0.0800 | 1.6000 | 0.1120 |
| 1700.0 | -0.0210 | 0.0000 | 0.0150 | 0.0850 | 1.7000 | 0.1190 |
| 1800.0 | -0.0286 | 0.0000 | 0.0204 | 0.0900 | 1.8000 | 0.1260 |
| 1900.0 | -0.0368 | 0.0000 | 0.0263 | 0.0950 | 1.9000 | 0.1330 |
| 2000.0 | -0.0457 | 0.0000 | 0.0327 | 0.1000 | 2.0000 | 0.1400 |

Z Axis Data. Linear units are mm, angular units are mm/m.

| Pos | Lx | Ly | Lz | Rx | Ry | Rz |
|---|---|---|---|---|---|---|
| 0.0 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| -100.0 | -0.0029 | 0.0026 | 0.0000 | -0.0090 | -0.0100 | -0.0110 |
| -200.0 | -0.0047 | 0.0043 | 0.0000 | -0.0180 | -0.0200 | -0.0220 |
| -300.0 | -0.0056 | 0.0050 | 0.0000 | -0.0270 | -0.0300 | -0.0330 |
| -400.0 | -0.0055 | 0.0049 | 0.0000 | -0.0360 | -0.0400 | -0.0440 |
| -500.0 | -0.0043 | 0.0039 | 0.0000 | -0.0450 | -0.0500 | -0.0550 |
| -600.0 | -0.0022 | 0.0020 | 0.0000 | -0.0540 | -0.0600 | -0.0660 |
| -700.0 | 0.0009 | -0.0008 | 0.0000 | -0.0630 | -0.0700 | -0.0770 |
| -800.0 | 0.0051 | -0.0046 | 0.0000 | -0.0720 | -0.0800 | -0.0880 |
| -900.0 | 0.0102 | -0.0092 | 0.0000 | -0.0810 | -0.0900 | -0.0990 |
| -1000.0 | 0.0163 | -0.0147 | 0.0000 | -0.0900 | -0.1000 | -0.1100 |

This data is generated based on the increment values shown at the top of the data view. The map can be interpolated to any desired increment by editing the increment fields at the top of the display and pressing the *Update* button.

*This data is provided to show the end result of all machine errors following the interpretation of the error expressions. This data is not used for calculation of the measurement errors therefore the input map increments have no affect on any calculated measurement result.*

## Revision History

| *Date* | *Version* | *Changes* |
|---|---|---|
| July 27, 2016 | 1.0 | New Program |
| July 28, 2016 | 1.0.1 | Revision of documentation regarding expression constants. |
| Aug 6, 2016 | 1.1 | Added option to specify a mechanical rotation point independent of the mathematical rotation point. |
| Nov 6, 2016 | 1.2 | [bugfix] Wrong IJK surface normal values sent to OpenGL<br>Added minimum offset before drawing knuckle probes. |
| Dec 14, 2016 | 2.0 | [bugfix] Software crash for horizontal arm when measurements exceed axis length.<br>Improvements to selection. Added selection highlight.<br>Switched to newer OpenGL base class.<br>Added option to detect minimum usable OpenGL version and disable sections of the program that are not compatible. |
| Apr 25, 2018 | 2.1 | [bugfix] Ballbar measurement data was created without the probe offset included in the position of each sphere.<br>[bugfix] Ballbar data had an incorrect title label. |
| Nov 28, 2018 | 2.2 | [bugfix] Probe offset offsetting map axis positions.<br>Added expression builder |
| Aug 30, 2023 | 3.0 | Rewrite to make utility more intuitive. |
| Jan 25, 2025 | 4.0 | [bugfix] Selected and reported deviations differ with large machine errors.<br>[bugfix] No units displayed for map data.<br>[bugfix] Cannot cancel evaluation report generation.<br>Updated toolbar icons.<br>Sorting enabled for machines and measurements.<br>Renamed ISO to 10360-2.<br>Updated the auto generate measurement name routine. |
| May 24, 2025 | 5.0 | [bug fix] Z axis scale errors not used in map data.<br>[bug fix] Axis signs based on first axis setting only.<br>Added 10360 ballbar artifact option.<br>Changed how Probe offsets are drawn.<br>Added option to remember last used export location.<br>Updated naming convention.<br>Changed name of machine scale error sign options. |