Squareness Calculator Users Guide

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Introduction

The Squareness Calculator is a utility that can calculate squareness corrections directly from a set of length measurements on a CMM. The measurements of length can be from a ball bar or from artifacts such as step gauges, gauge blocks, or a laser interferometer.

The sample data supplied with this utility program solve to 100, 200, and 300 um/m for the XY, YZ, and ZX squareness errors. The sample measurement data has been somewhat randomized to demonstrate the capabilities of the Squareness Calculator utility and can be used to evaluate other calculation methods.

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

Overview

The Squareness Calculator utility consists of a graphical view of the data, a data editor, and the calculated results. The calculated results are shown below the measurement model.

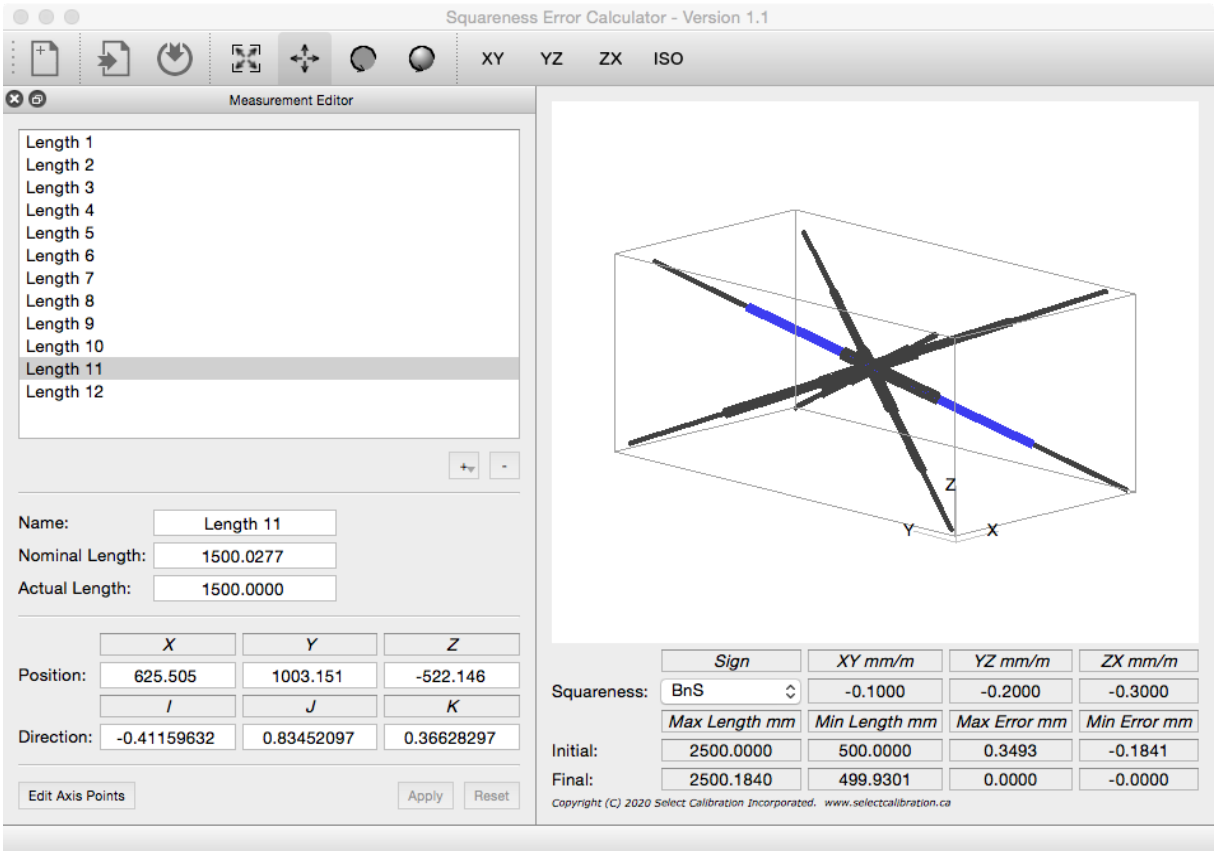


Illustration 1: Squareness error calculated from a set of four diagonal laser measurements consisting of twelve measurement lengths.

The Squareness Calculator uses the measurement position and orientation when solving for the squareness corrections which can have an impact on the correctness of the final result particularly under real world conditions. The sample data provided with this utility has orientations that are somewhat random but always solve to the same correction values when using the Squareness Correction utility.

There are no required measurement patterns or naming convention that is necessary in order to use the Squareness Calculator utility. Each measurement is evaluated using the measurement position and orientation to decide what contribution it provides to any of the three squareness projection planes.

When using a ball bar the processed average length of all measurements becomes the nominal for each and every ball bar position. The nominal length for any ball bar position cannot be changed directly.

Measurements using artifacts such as gauge blocks, step gauges, or a laser interferometer will have unique nominal value for each length measurement. There is no requirement that all measurements have the same nominal length. The sample diagonal laser measurement data has three different lengths along each of the four measurement lines resulting in twelve unique measurements.

Any pattern of ball bar measurements can be used or any combination of length measurements can be used. A combination of ball bar and length measurements can be used if desired.

The corrections produced by the Squareness Calculator can be directly added to the existing squareness data from the CMM's compensation error map. The selection of the type of compensation map changes the sign to be suitable for those common error map formats.

Measurement of four 3D diagonal lines through the CMM volume is a common pattern used by 10360-2 and the primary reason this utility program was written. The secondary reason for this program was to test the light weight 3D graphics window.

Measurement Editor

The measurement editor allows direct input or modification of measurement data. Changes made to any of the editable fields must be accepted or discarded using either *Apply* or *Reset.*

The measurement editor can be separated from the main window and floated or even hidden. Selected measurements are highlighted in the graphics display with a bright green color. The visibility of the measurement editor can be controlled from the *View* menu. Illustration 2 shows an example of the *Measurement Editor* widget.

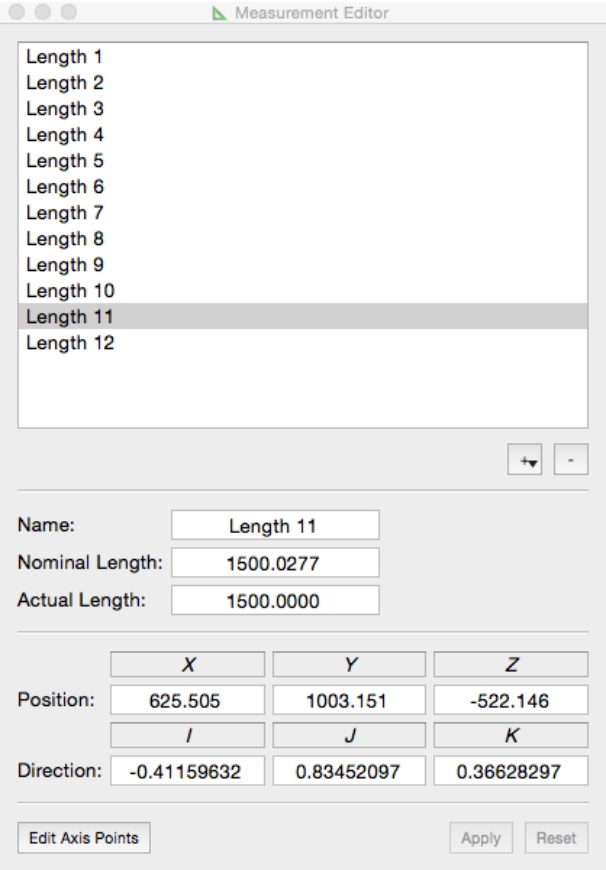


Illustration 2: Measurement editor showing details from the selected measurement.

Options:

Option	*Description*
Add Button	Add a new ball bar or length measurement.
Remove Button	Delete selected measurements.
Name	Name of the measurement as it appears in the list of measurements.
Nominal Length	For non-ball bar items this is the nominal length of the measurement. The nominal length of a ball bar is the processed mean of all ball bar length data and cannot be manually entered.
Actual Length	Actual measured length.
Position XYZ	Center location of the measurement.
Direction IJK	Direction of the measurement line.
Edit Axis Points	Editor to allow modification of the center position and direction by inputting a start and end point instead of a center point and direction.
Apply	Save changes and update.

Option	*Description*
Reset	Restore all fields to values prior to change.

Edit Axis Points

This option allows setting the measurement position and direction by entering two points that represent the start and the end of the measurement. An example of this editor is shown in illustration 3.

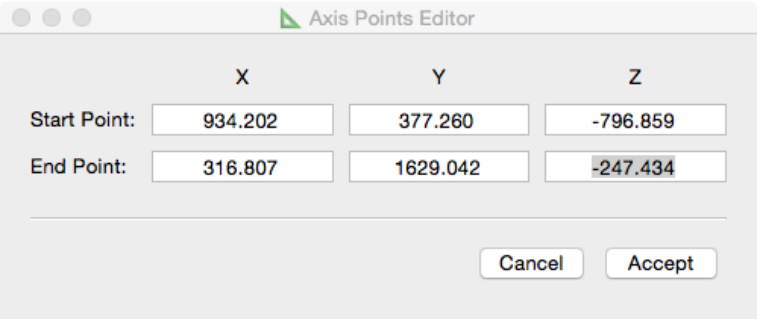


Illustration 3: Axis point editor dialog.

The center position of the measurement is assumed to be in the middle of the two points. The axis direction is the normalized vector of the end point relative to the start point.

The Axis Point Editor does not change the nominal or actual measurement length. It only affects the measurement position and direction.

Calculation Output

The output of the Squareness Calculator utility is shown in illustration 4. This information is displayed below the graphic window.

	Sign	*XY mm/m*	*YZ mm/m*	*ZX mm/m*
Squareness:	BnS	-0.1000	-0.2000	-0.3000
	Max Length mm	*Min Length mm*	*Max Error mm*	*Min Error mm*
Initial:	2500.0000	500.0000	0.3493	-0.1841
Final:	2500.1840	499.9301	0.0000	-0.0000

Illustration 4: Calculation output data.

Output Field:

Option	*Description*
Sign	Selection of the type of compensation error map on the machine. The correction signs will be correct if the error map selection type is correct.
Squareness XY, YZ, ZX	Calculated squareness correction values for the XY, YZ, and ZX projection planes. To remove this error simply add these numbers to the existing squareness errors in the compensation error map.

Option	*Description*
Max Length	The length of the longest measurement.
Min Length	The length of the shortest measurement.
Max Error	The largest positive error in the measurement data. It may be the smallest negative error if the max and min are both negative.
Min Error	The largest negative error in the measurement data. It may be the smallest positive error if the max and min are both positive.
Initial	Calculations from the input data.
Final	Estimation of the amount of residual error following the squareness correction.

Initial and Final Results

The initial and final results show the measurement error before and after removal of the displayed squareness errors. Adding the calculated correction values to the existing compensation squareness data and then repeating the pattern measurement should show results very close or identical to what is displayed in this section of the output.

The sample data provided with this program should always produce corrections of 100, 200, and 300 um/m for the XY, YZ, and ZX squareness errors with virtually zero residual error. When using actual measurement data from a CMM the measurement noise and contributions from non-squareness errors will result in some residual error in the final calculated results.

The best scenario for updating squareness errors on a CMM is to use a combination of measurements throughout the machines volume. Non-squareness errors in the machine will have an impact on the local squareness errors throughout the measurement volume so try to sample as much of the machine as possible.

Graphics Display

The graphics display of the Squareness Calculator uses a custom widget that does not use hardware acceleration. The advantage of this is a smaller foot print and reduced requirements from the operating systems that run this utility. There are many disadvantages from not using a 3D graphics library such as not having a solid model or depth testing but for the purpose of the Squareness Calculator this is not important.

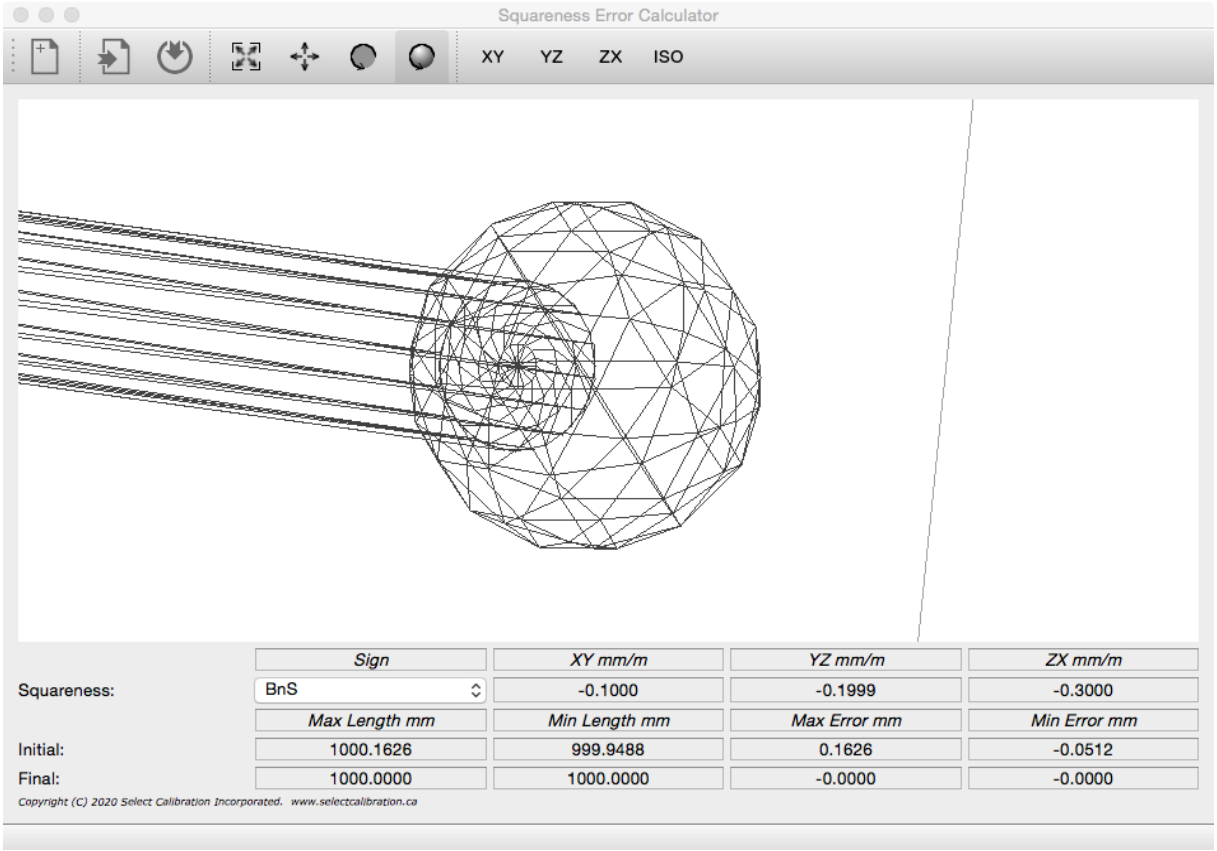


Illustration 5: Graphics display window. The selected measurement items are shown in green.

The graphics display is not fixed and can be manipulated in a variety of ways. The mode options define what happens when using the right mouse button on the model window (or mouse button with the CTRL button down when using a single button mouse).

Image	*Description*
	Scale to fit. Adjusts the scale of the 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.
	Set the display to show the model in the XY projection plane.

Image	*Description*
	Set the display to show the model in the YZ projection plane.
	Set the display to show the model in the ZX projection plane.
	Set the display to show the model in an isometric view.

In addition to the above controls areas of the displayed model can be zoomed by drawing a box around sections of interest. The scale of the model can be increased or decreased using the mouse scroll button. A right mouse click above or below the horizontal centerline will zoom in or out of the model.

Menu Options

The menu and menu toolbar of the Squareness Calculator utility has the following options:

Image	*Menu Item*	*Description*
	File - New	Clear existing measurement data.
	File - Open	Load a previously created squareness measurement file.
	File - Save	Save the current squareness measurement data to a file.
	File – Save As	Save the current squareness measurement data to a file with a different name or location.
	File - Import	Import either a ball bar or laser measurement file. The imported file must be one of the supported formats.
	File - Quit	Close the Squareness Calculator utility.
	View – Measurement Editor	Toggles the visibility of the measurement editor widget.
	Help – About	Display the version of the Squareness Calculator utility.

Import File Formats

Measurement data can be imported by using the option *File – Import* or with drag and drop. The type of imported file is determined from the contents. The Squareness Calculator can import the following file types:

- Ball Bar data version 1.
- Ball Bar data version 2.
- Ball Bar data version 3.
- Laser data version 1.

Ball Bar Version 1 Format

Example:

```
BallBar_V1
P1,900.027,995.493,275.063,-1279.898,992.027,921.082,-653.243,0,0,-201.5
P2,900.024,749.617,337.792,-1280.071,1196.835,803.275,-652.882,0,0,-201.5
P3,900.022,618.316,545.266,-1278.162,1262.635,584.342,-650.973,0,0,-201.5
…
```

Comments:

- First line must be *BallBar_V1*
- Each data line in the file must contain 11 comma separated entries.
- XYZ position of each sphere does not include the probe offset.
- No practical limit to the number of measurement entries.
- Comment lines begin with the hash symbol (#).

Line Entry:

Name, Length, X1, Y1, Z1, X2, Y2, Z2, PrbX, PrbY, PrbZ

Where:

Name = ball bar measurement position name
Length = actual measured length of ball bar
<XYZ> = X, Y, and Z position of each ball bar sphere
<PRB> = XYZ probe offset. Sign of offset is normal to machine (reversed from PC-DMIS offsets).

Ball Bar Version 2 Format

Example:

```
BallBar_V2
P1,900.027,995.493,275.063,-1279.898,992.027,921.082,-653.243,0.000,0.000,0,0,-201.5
P2,900.024,749.617,337.792,-1280.071,1196.835,803.275,-652.882,0.000,0.000,0,0,-201.5
P3,900.022,618.316,545.266,-1278.162,1262.635,584.342,-650.973,0.000,0.000,0,0,-201.5
…
```

Comments:

- First line must be *BallBar_V2*
- Each data line in the file must contain 13 comma separated entries.
- XYZ position of each sphere does not include the probe offset.
- No practical limit to the number of measurement entries.
- Comment lines begin with the hash symbol (#).

Line Entry:

Name, Length, X1, Y1, Z1, X2, Y2, Z2, Sf1, Sf2, PrbX, PrbY, PrbZ

Where:

Name = ball bar measurement position name
Length = actual measured length of ball bar
<XYZ> = X, Y, and Z position of each ball bar sphere
<Sf> = Measured form error of the ball bar sphere.
<Prb> = XYZ probe offset. Sign of offset is normal to machine (reversed from PC-DMIS offsets).

Ball Bar Version 3 Format

Example:

```
B89.4.1_Data:Version=1:Type=BallBar
P1,900.027,995.493,275.063,-1279.898,992.027,921.082,-653.243,0.000,0.000,0,0,-201.5
P2,900.024,749.617,337.792,-1280.071,1196.835,803.275,-652.882,0.000,0.000,0,0,-201.5
P3,900.022,618.316,545.266,-1278.162,1262.635,584.342,-650.973,0.000,0.000,0,0,-201.5
…
```

Comments:

- First line must be *B89.4.1_Data:Version=1:Type=BallBar*
- Each data line in the file must contain 13 comma separated entries.
- XYZ position of each sphere includes the probe offset.
- No practical limit to the number of measurement entries.
- Comment lines begin with the hash symbol (#).

Although this version is technically the third data format for ball bar measurements it was named as a type 1 format. It is the first version of the ball bar data file that uses the naming format typical of SCI.

Line Entry:

Name, Length, X1, Y1, Z1, X2, Y2, Z2, Sf1, Sf2, PrbX, PrbY, PrbZ

Where:

Name = ball bar measurement position name
Length = actual measured length of ball bar
<XYZ> = X, Y, and Z position of each ball bar sphere
<Sf> = Measured form error of the ball bar sphere.
<PRB> = XYZ probe offset. Sign of offset is normal to machine (reversed from PC-DMIS offsets).

Laser Version 1 Format

This format is used primarily for the measurement of diagonals on a CMM with a laser but can be adapted to any kind of length measurement or equipment. A measurement is performed along the diagonal body line then broken down into individual measurement lengths.

As an example, assume a length of 2500 mm is measured at increments of 500 mm. From this data you have a length measurements of 2500 mm (step 5 to step 0), a length measurement of 1500 mm (step 4 to step 1), and a length measurement of 500 mm (step 3 to step 2). Extracting three measurement lengths from the five target positions (the sixth target is zero) is common.

It is possible to extract several more lengths from the 5 (6 with zero) target positions then the three that are shown. Measuring more than 5 target positions along the diagonal measurement line will also allow more extractions of measurement length from the data. The standard set of 5 targets provides a good symmetrical set of three length measurements and is reasonably fast.

Example:

```
Length_Data:Version=1:Type=Measurement
:Data_Begin
Probe_Offset:0.00000,0.00000,-75.00000
   10.000,  -20.000, -970.000, 1107.720, 2051.350, -101.369, 2499.650, 2499.999
  229.544,  394.270, -796.273,  888.176, 1637.080, -275.095, 1499.790, 1499.999
  449.088,  808.540, -622.547,  668.632, 1222.810, -448.821,  499.930,  499.999
:Data_End
:Data_Begin
Probe_Offset:0.00000,0.00000,-75.00000
   60.000, 2150.000, -960.000, 1134.363,   88.383,  -40.499, 2500.121, 2499.999
  274.872, 1737.676, -776.099,  919.490,  500.706, -224.399, 1500.073, 1499.999
  489.745, 1325.353, -592.199,  704.618,  913.030, -408.299,  500.024,  500.000
:Data_End
...
```

Comments:

- First line must be *Length_Data:Version=1:Type=Measurement*
- Each data line in the file must contain 8 comma separated values.
- Measurements must be surrounded by separate *:Data_Begin* and *:Data_End lines* or the measurement data entries will be ignored.
- Probe offset must be added for each measurement block. All entries inside a data block use the same probe offset.
- Comment lines begin with the hash symbol (#).

Line Entries:

Probe_Offset: X, Y, Z
X1, Y1, Z1, X2, Y2, Z2, Nominal, Actual

Where:

Probe_Offset: <XYZ> = XYZ probe offset. Sign of offset is normal to machine (reversed from PC-DMIS offsets).
<XYZ> = X, Y, and Z position of each point of the measurement line
<Nominal> = Nominal length of the measurement.
<Actual> = Actual measured length.

When using a laser the laser is the nominal and the machine represents the actual. In the above example the nominal shows the error while the actual shows almost no error. It is common practice to treat the data from the laser as the measured and the machine as the nominal instead of the more logical reverse. This practice should be avoided and doesn't make sense in general.

Suggestions for Manual Data Entry

When measuring body diagonals of a machine a reasonable IJK value can be entered by simply entering the dimensions of the CMM. An example showing the calculation for a body diagonal of a Global 12.22.10 CMM is shown in illustration 6.

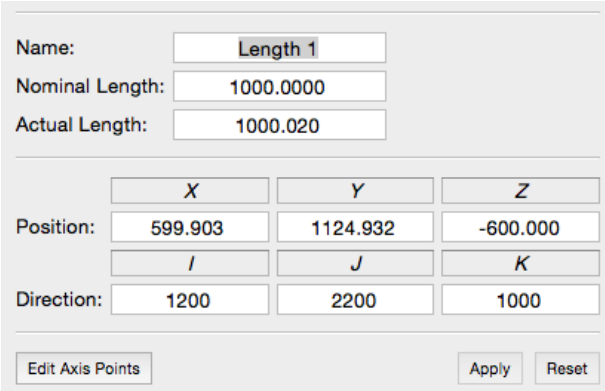


Illustration 6: Using CMM dimensions for the description of the measurement direction.

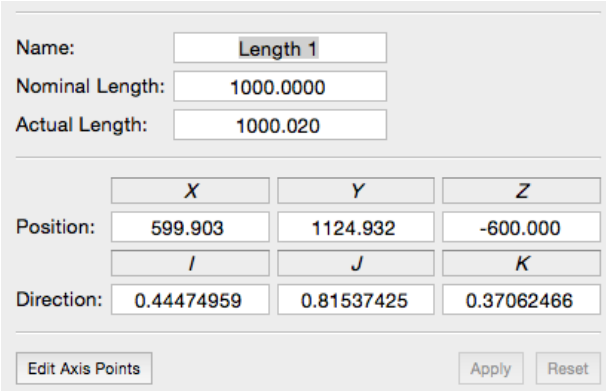


Illustration 7: Updated IJK direction based on the CMM dimensions.

The option Edit Axis Points can be used to set the approximate position and measurement direction by using the CMM DRO display. Position the machine at the location of the measurement and record the XYZ position in the DRO display (it must be in machine coordinates) and use the Edit Axis Points dialog to turn this into a center position and direction.

It is preferable to have the position data written to a file in one of the supported formats. This is the least error prone option and will provide the best results from the Squareness Calculator utility.

Approximation Errors

When measurement lines have approximated position or direction data it will contribute to the calculation error. The Squareness Calculator utility can be used to estimate the error from data approximation. Two examples were chosen where the first was a basic XY squareness from two ball bar measurements and the second from using four 3D diagonal ball bar positions.

Squareness From Two Ball Bar Measurements

The measurement of one squareness projection plane can be done with only two ball bar positions. In this example the XY squareness error is of interest and the two positions are in the XY plane at approximately 45 degrees to the primary axis. Referring to illustration 9 and illustration 10 and depending on the kind of machine or ball bar kit this could be a practical measurement example.

Since the ball bar measurements are not flat into the XY projection plane the YZ and ZX squareness errors were not included in this particular test data as the other squareness errors would have influenced these results.

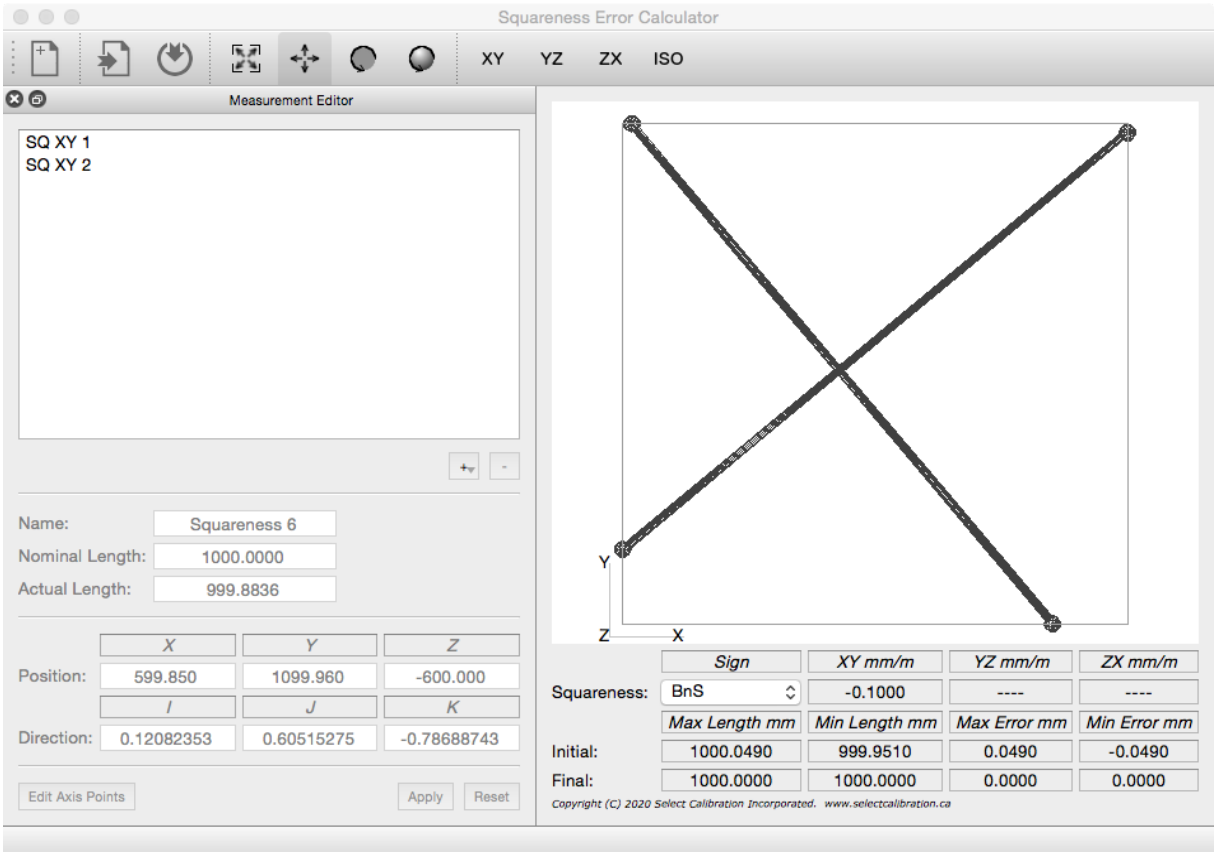


Illustration 8: Measurement of XY squareness example

Illustration 9: View from ZX projection plane

Illustration 10: View from YZ projection plane

Measurement	*Item*	*Value*
SQ XY 1	Length	1000.04898 mm
	ABS Angle from X Axis	39.8 degrees
	ABS Angle from XY Plane	3.7 degrees

Measurement	*Item*	*Value*
SQ XY 2	Length	999.95102 mm
	ABS Angle from X Axis	50.2 degrees
	ABS Angle from XY Plane	3.7 degrees

Using the Squareness Calculator the IJK vector for each measurement axis was set to the nominal 45 degrees relative to the X axis. The result is shown in illustration 11.

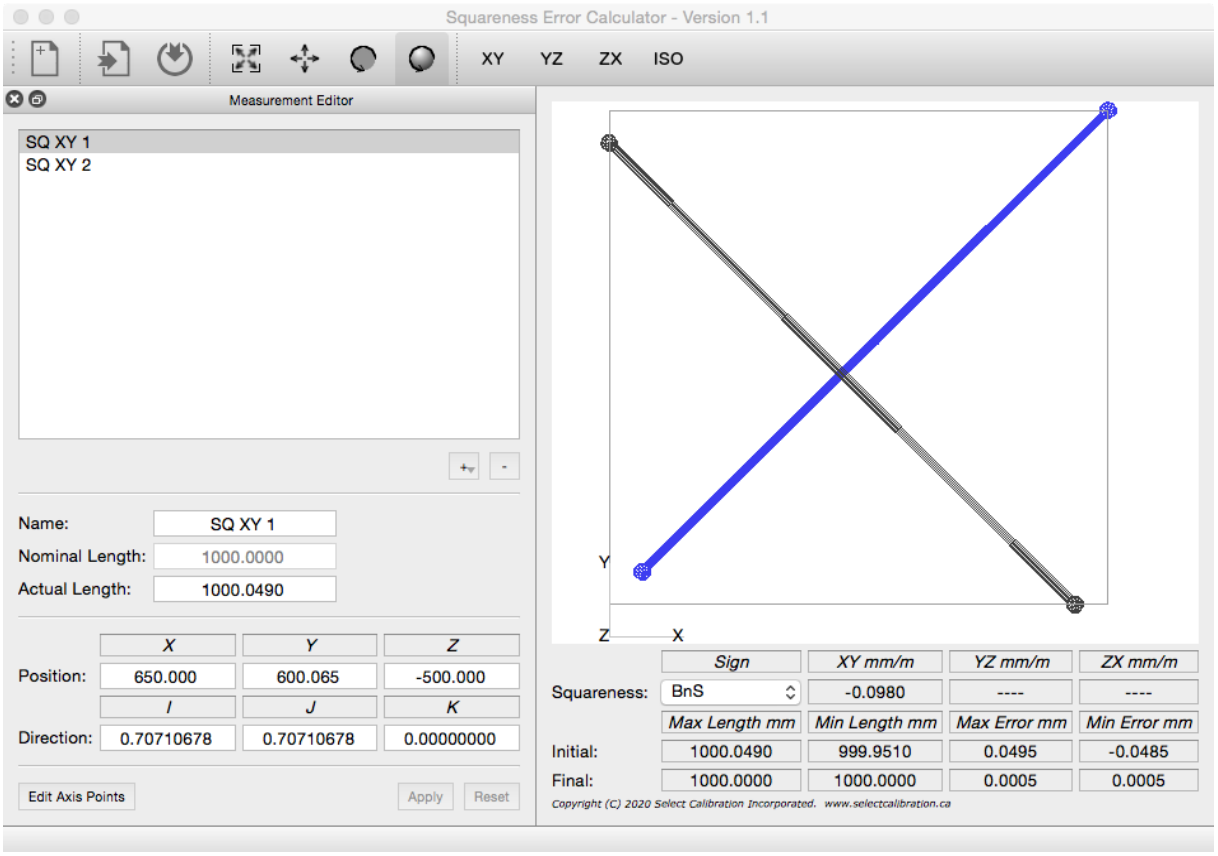
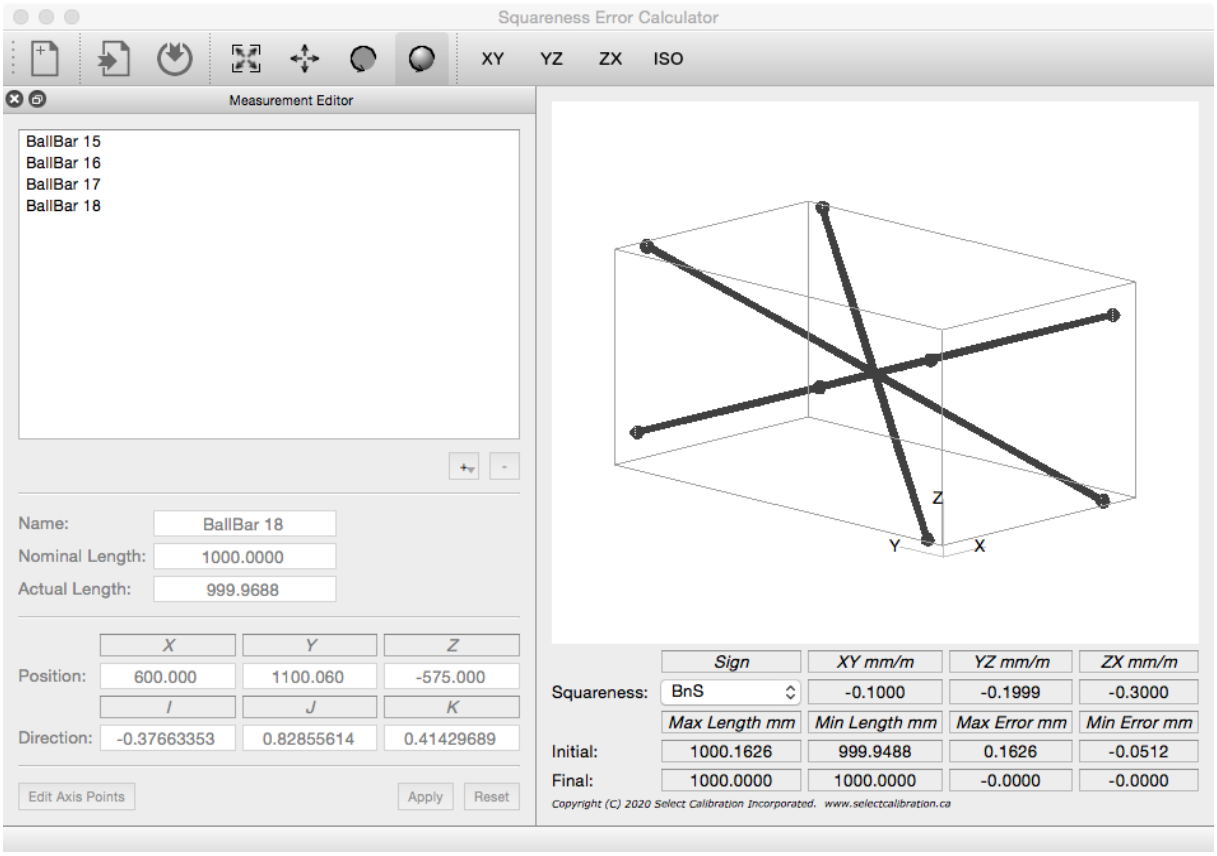


Illustration 11: Measurement result using a nominal measurement axis.

The error exists but is relatively small (2% of the known error or 98 um/m instead of the expected 100 um/m).

Squareness From Four 3D Diagonal Ball Bar Measurements

The XY, YZ, and ZX squareness errors can be extracted from four 3D ball bar measurements. The orientation of each measurement line is more critical than the previous 2D example as each measurement line is a less direct measurement of any squareness error.

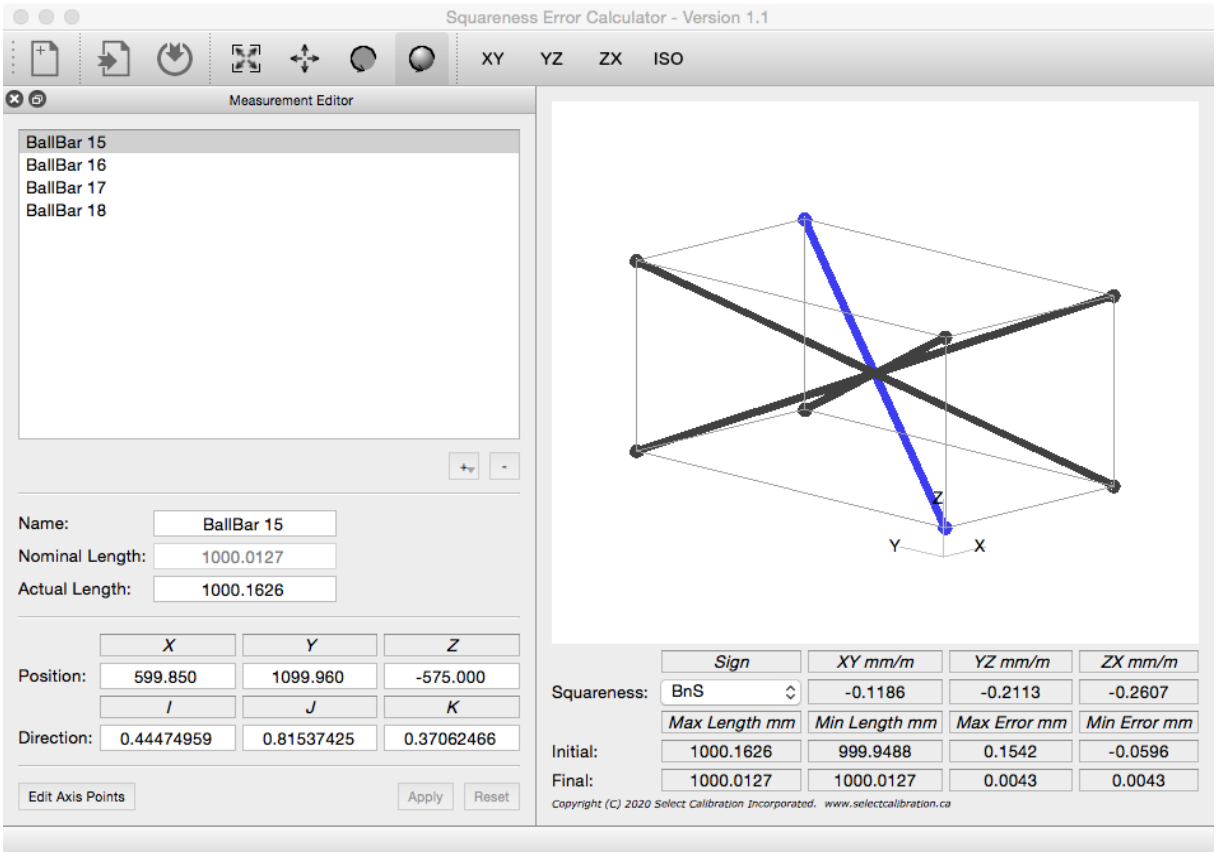


Measurement	*Item*	*Value*
BallBar 15	Length	1000.1626 mm
	Nominal Axis IJK	0.44474959, 0.81537425, 0.37062466
	Angle from Nominal Axis	4.6 degrees

Measurement	*Item*	*Value*
BallBar 16	Length	999.9488 mm
	Nominal Axis IJK	0.44474959, -0.81537425, 0.37062466
	Angle from Nominal Axis	5.2 degrees

Measurement	*Item*	*Value*
BallBar 17	Length	999.9489 mm
	Nominal Axis IJK	-0.44474959, -0.81537425, 0.37062466
	Angle from Nominal Axis	5.9 degrees

Measurement	*Item*	*Value*
BallBar 18	Length	999.9906 mm
	Nominal Axis IJK	-0.44474959, 0.81537425, 0.37062466
	Angle from Nominal Axis	4.7 degrees



The error is noticeably larger than the what was observed from the 2D squareness example (approximate average error is 13% of the known error). When generating test data it was desired to keep the shift in orientation around 5 degrees which is similar to what was used for the 2D squareness example. When testing on an actual machine it is more likely to have orientation errors greater than 5 degrees for the 3D diagonals.

Revision History

Date	*Version*	*Changes*
Jan 26, 2020	1.0	New Program
Mar 30, 2020	1.1	[bug fix] Nominal ball bar length not visually updated. Added Renishaw sign option. Changed selection color from green to blue.