

# Squareness Calculator Users Guide

## Table of Contents

Introduction.....	3
Overview.....	3
Measurement Editor.....	4
Edit Axis Points.....	6
Calculation Output.....	6
Initial and Final Results.....	7
Graphics Display.....	7
Menu Options.....	9
Import File Formats.....	9
Ballbar Legacy Format 1.....	10
Ballbar Legacy Format 2.....	10
Ballbar Current Format.....	11
Laser Version 1 Format.....	11
Step Gauge Squareness Version 1 Format.....	12
MeasureDirect Version 1 Laser Data.....	14
BnS Service Utilities Results File.....	16
Ballbar 10360 Version 1 Format.....	16
Suggestions for Manual Data Entry.....	18
Approximation Errors.....	19
Squareness From Two B89.4.1 Ballbar Measurements.....	19
Squareness From Four 3D Diagonal B89.4.1 Ballbar Measurements.....	21
Squareness From Four 3D Diagonal 10360 Ballbar Measurements.....	23
Revision History.....	26

# Squareness Calculator Users Guide

## Introduction

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

The sample data supplied with this utility solve to nominal corrections of 100, 200, and 300  $\mu\text{m/m}$  for the XY, YZ, and ZX squareness errors. The sample measurement data has been somewhat randomized to demonstrate the capabilities of the *Squareness Calculator* and can be used to evaluate other calculation methods.

## Overview

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

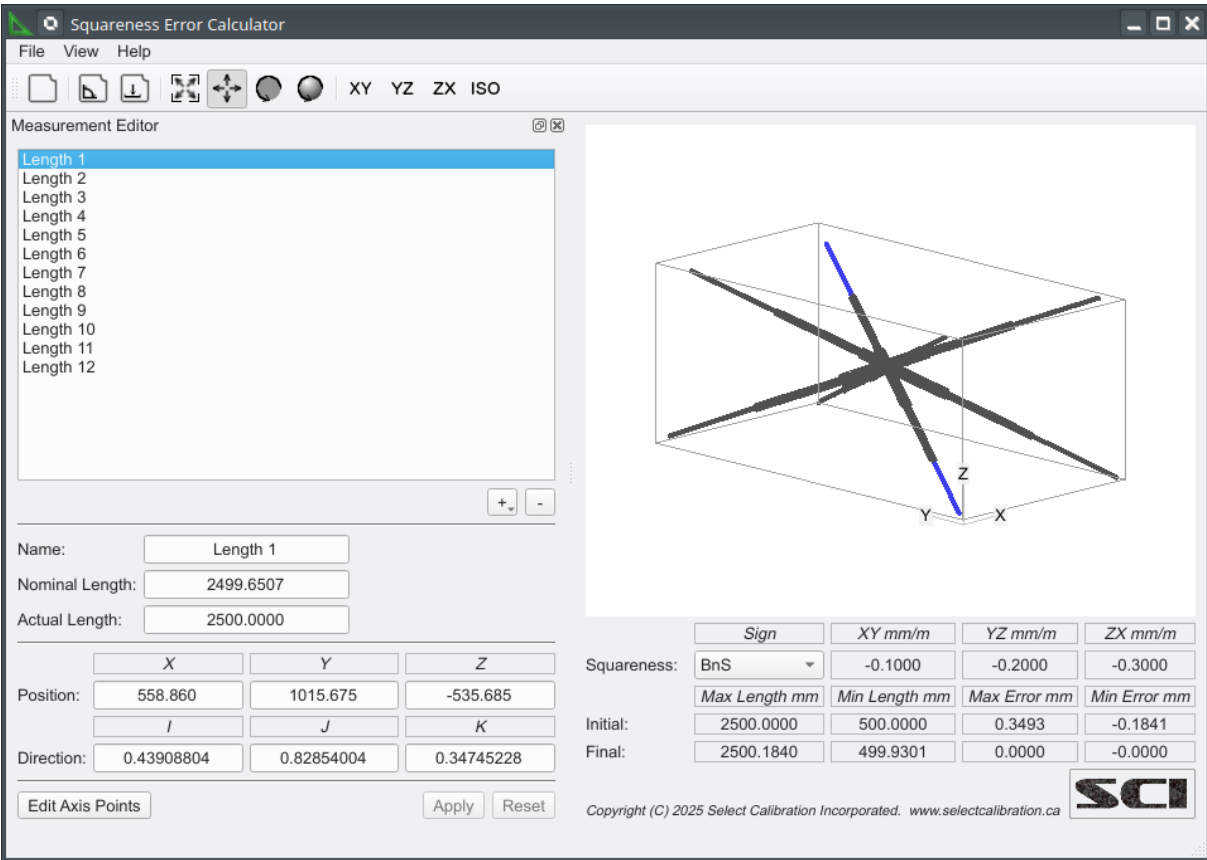


Illustration 1: Squareness error calculated from a set of four diagonal laser measurements consisting of twelve measurement lengths.

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 always solve to the same correction values when using the *Squareness Calculator* utility.

## Squareness Calculator Users Guide

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

When using a B89.4.1 ballbar the average length of all measurements becomes the nominal for all ballbar positions and cannot be changed directly. Measurements using artifacts such as gauge blocks, step gauges, 10360 ballbar, or a laser interferometer will have a unique nominal value for each length measurement. There is no requirement that all measurements have the same nominal length. Any pattern of ballbar or length measurements or combinations of measurement types can be used.

The corrections produced by the *Squareness Calculator* are intended to 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. The measurement editor can be separated from the main window, floated, or even hidden. Selected measurements are highlighted in the graphics display with a blue color. The visibility of the measurement editor can be controlled from the *View* menu. Illustration 2 shows an example of the *Measurement Editor* widget.

# Squareness Calculator Users Guide

The screenshot shows a software window titled "Measurement Editor". At the top is a list of measurements from "Length 1" to "Length 12", with "Length 11" highlighted in blue. Below the list are two buttons, "+" and "-". The main section contains input fields for "Name:" (Length 11), "Nominal Length:" (1500.0277), and "Actual Length:" (1500.0000). Below these are three columns for position and direction: X, Y, Z and I, J, K. The X, Y, Z fields contain 625.505, 1003.151, and -522.146 respectively. The I, J, K fields contain -0.41159632, 0.83452097, and 0.36628297 respectively. At the bottom are three buttons: "Edit Axis Points", "Apply", and "Reset".

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

The example measurement shown in illustration 2 is typical of a measurement from a laser. When using a laser the actual length is the distance the machine was told to move and the nominal is the distance reported by the laser. The data from the laser is always used as the nominal.

*With rare exception the machine will never move to exact target coordinates so the actual length is expected to show some error.*

Table 1: Measurement Editor Options:

Option	Description
Add Button	Add a new B89.4.1 ballbar or length measurement. 10360 ballbars are considered to be length measurements.
Remove Button	Delete the selected measurements.
Name	Name of the measurement as it appears in the list of measurements.
Nominal Length	Nominal length of the measurement. The nominal length of a B89.4.1 ballbar is the mean of all ballbar lengths and cannot be directly input.
Actual Length	Actual measured length.
Position XYZ	Center location of the measurement.

# Squareness Calculator Users Guide

Option	Description
Direction IJK	Axis of the measurement line.
Edit Axis Points	Allow modification of the center position and direction using two points.
Apply	Save changes and update calculated squareness.
Reset	Restore all fields to previous values.

## Edit Axis Points

This option updates the measurement position and axis using two points that represent the start and the end of the measurement. An example of this editor is shown in illustration 3.

The 'Axis Points Editor' dialog box contains two rows of input fields. The first row is labeled 'Start Point:' and the second row is labeled 'End Point:'. Each row has three input fields for X, Y, and Z coordinates. The X values are 934.202 and 316.807. The Y values are 377.260 and 1629.042. The Z values are -796.859 and -247.434. At the bottom right are 'Cancel' and 'Accept' buttons.

	X	Y	Z
Start Point:	934.202	377.260	-796.859
End Point:	316.807	1629.042	-247.434

Illustration 3: Axis point editor dialog.

The position of the measurement is the middle of the start and end points. The axis direction is the normalized vector of the end point relative to the start point.

*The Axis Point Editor only updates the measurement position and orientation and does not affect the measurement lengths.*

## Calculation Output

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

Table 2: Calculation Output Fields:

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	Calculated squareness correction values for the XY, YZ, and ZX projection planes.

## Squareness Calculator Users Guide

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Option	Description
XY, YZ, ZX	To remove this error from the CMM add these values to the existing squareness errors in the error map.
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 of error before any squareness correction.
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 squareness errors. Adding the calculated correction values to the existing compensation squareness data and then repeating the measurement pattern should show results identical or very close 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. Uncorrected geometry errors in the machine will have an impact on the local squareness errors throughout the measurement volume and can be minimized by sampling 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 solid views or depth testing but for the purpose of the *Squareness Calculator* this is not important.

# Squareness Calculator Users Guide

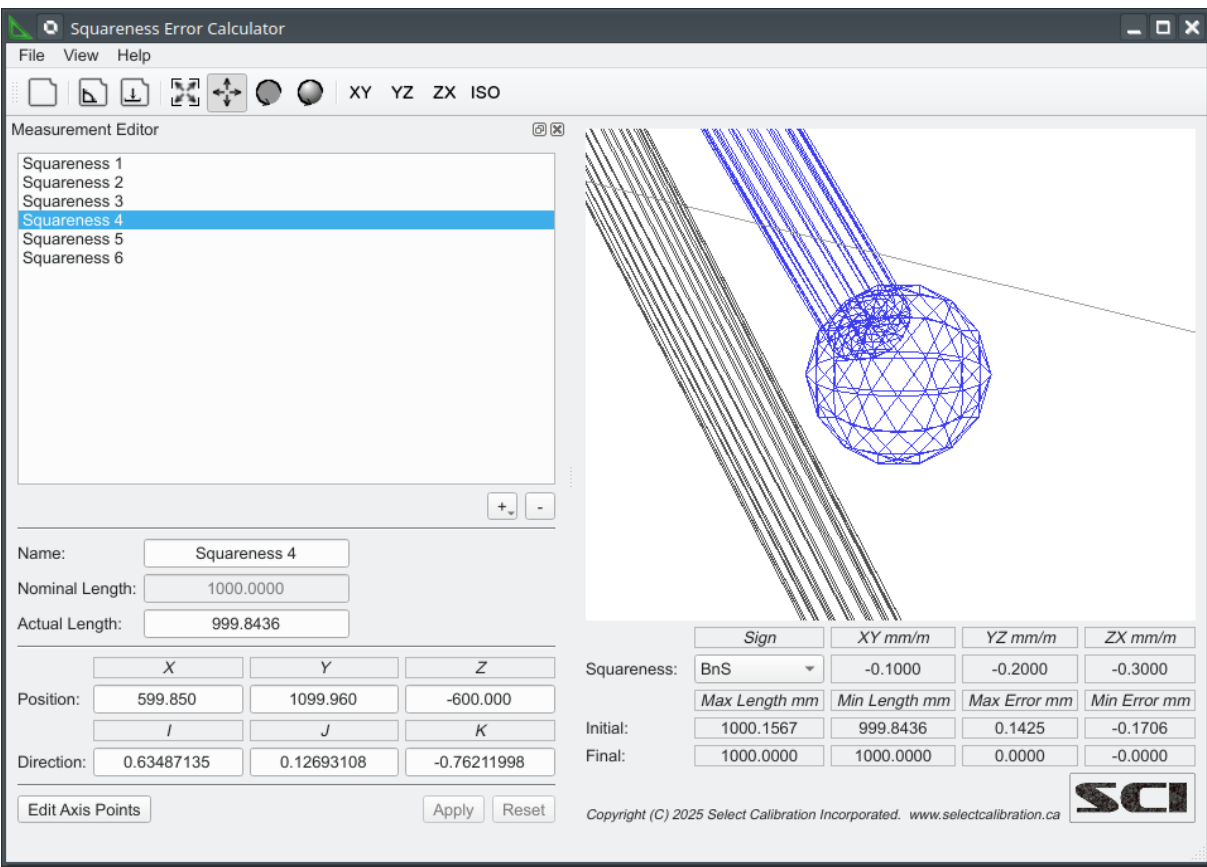


Illustration 5: Graphics display window. The selected measurement items are shown in blue.

The graphics display is not fixed and can be manipulated in a variety of ways. The selected option of the main toolbar defines the action when using the right mouse button on the model display. For operating systems such as MacOS it is necessary to click the CTRL button to recreate the right mouse button.




Table 3: Graphics Display Options:

Icon	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.
	Rotate 2D Mode. When enabled a right mouse button click and drag will rotate the model around the center of the viewport.
	Rotate 3D Mode. When enabled a right mouse button click and drag will rotate the model around the click position on the displayed model.
	Set the display to show the measurements in the XY projection plane.



## Squareness Calculator Users Guide

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Icon	Description
	Set the display to show the measurements in the YZ projection plane.
	Set the display to show the measurements in the ZX projection plane.
	Set the display to show the measurements in an isometric view.

The displayed measurements can be further inspected 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:

Table 4: Menu Options:

Icon	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 a measurement file in one of the supported formats.
	File - Quit	Close the <i>Squareness Calculator</i> utility.
	View - Measurement Editor	Toggles the visibility of the measurement editor widget.
	Help - About	Display the version of the <i>Squareness Calculator</i> utility.

### Import File Formats

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

- Legacy ballbar version 1.
- Legacy ballbar version 2.
- Current ballbar version 1.
- Laser data version 1.
- Step gauge squareness version 1.
- MeasureDirect version 1 laser data.
- BnS Service Utilities result file.

# Squareness Calculator Users Guide

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- Ballbar 10360 version 1.

## Ballbar Legacy Format 1

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 in map coordinates (position without 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 = ballbar measurement position name

Length = actual measured length of ballbar

<XYZ> = XYZ position of each ballbar sphere

<PRB> = XYZ probe offset. Sign of offset is normal to machine (reversed from PC-DMIS offsets).

## Ballbar Legacy Format 2

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 in map coordinates (position without 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 = ballbar measurement position name

# Squareness Calculator Users Guide

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Length = actual measured length of ballbar

<XYZ> = XYZ position of each ballbar sphere

<Sf> = Measured form error of the ballbar sphere.

<Prb> = XYZ probe offset. Sign of offset is normal to machine (reversed from PC-DMIS offsets).

## Ballbar Current 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 including 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 ballbar measurements it was named as a type 1 format as it is the first version of the ballbar data file using the naming format typical of SCI. The legacy B89.4.1 ballbar formats are no longer used but still recognized as an input.*

Line Entry:

Name, Length, X1, Y1, Z1, X2, Y2, Z2, SF1, SF2, PrbX, PrbY, PrbZ

Where:

Name = ballbar measurement position name

Length = actual measured length of ballbar

<XYZ> = XYZ position of each ballbar sphere

<SFx> = Measured form error of the B89.4.1 ballbar sphere 1 and sphere 2.

<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 squareness measurement along diagonals on a CMM using 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.*

# Squareness Calculator Users Guide

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## 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> = XYZ position of each point along 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.*

## Step Gauge Squareness Version 1 Format

This format is used primarily for the measurement of diagonals on a CMM with a step gauge. A measurement is performed along the diagonal body line then broken down into individual measurement lengths.

A typical squareness measurement will consist of seven points (six lengths) along the step gauge with the first length at the shortest measurable step of the step gauge. The number of measurement points and repeat count can be set to anything suitable by the part program

# Squareness Calculator Users Guide

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performing the measurement.

Example:

```
Stepgauge_Raw_Measurement:Version=1:Type=Squareness

Equipment_Identification:1520007

Alignment_Begin:
X_Axis:0.663413945757,-0.500000004822,0.556670397770
Y_Axis:-0.383021949868,-0.866025401000,-0.321394136134
Z_Axis:0.642787774071,0.000000370808,-0.766044305184
Translation:-3.37845,-0.73205,-0.22404
Alignment_End:

Probe_Offset:0.00000,0.00000,-194.00000
Probe_Vector:0.000000000000,0.000000000000,-1.000000000000

Measurement_Begin:

Description:Sql
Reference_Step_Position:0.000

Point:0,0,-0.00000,4.00000,-4.00001
Point:0,1,10.00000,4.00000,-4.00000
Point:0,2,210.00000,4.00000,-4.00000
Point:0,3,410.00000,4.00000,-4.00000
Point:0,4,610.00000,4.00000,-4.00000
Point:0,5,810.00000,4.00000,-4.00000
Point:0,6,1010.00000,4.00000,-4.00000

Point:1,0,-0.00000,4.00000,-4.00001
Point:1,1,10.00000,4.00000,-4.00000
Point:1,2,210.00000,4.00000,-4.00000
Point:1,3,410.00000,4.00000,-4.00000
Point:1,4,610.00000,4.00000,-4.00000
Point:1,5,810.00000,4.00000,-4.00000
Point:1,6,1010.00000,4.00000,-4.00000

Point:2,0,-0.00000,4.00000,-4.00001
Point:2,1,10.00000,4.00000,-4.00000
Point:2,2,210.00000,4.00000,-4.00000
Point:2,3,410.00000,4.00000,-4.00000
Point:2,4,610.00000,4.00000,-4.00000
Point:2,5,810.00000,4.00000,-4.00000
Point:2,6,1010.00000,4.00000,-4.00000

Measurement_End:
```

Comments:

- First line must be *Stepgauge\_Raw\_Measurement:Version=1:Type=Squareness*
- Alignment section indicates the orientation of the measurement with X along the gauge.
- Measurements must be surrounded by separate *Measurement\_Begin:* and *Measurement\_End:* entries or the measurement data entries will be ignored.
- Comment lines begin with the hash symbol (#).

Data Entries:

# Squareness Calculator Users Guide

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Point: <run>, <step>, X, Y, Z

Where:

<run> = zero based repeat counter

<step> = zero based step counter

<XYZ> = XYZ position of each point along the measurement line

*The entries for the Equipment\_Identification, Probe\_Offset, Probe\_Vector, and Reference\_Step\_Position are currently ignored by the Squareness Calculator utility. The nominal length is the measured length rounded to the nearest mm. For best results the nominal length of each individual length should be updated to the proper value particularly if the measurement diagonals differ in length or there is poor symmetry in the positions.*

## MeasureDirect Version 1 Laser Data

This format is generated by MeasureDirect when using a laser for data collection or 10360-2 testing. The 10360-2 measurement pattern will result in three unique measurement lengths and the number of measurement lengths from the data collection depends on the number of samples but will be no more than nine using the furthest data points.

### Example of MeasureDirect 10360-2 data:

```
B89.4.10360_Raw_Measurement:Version=1:Type=Machine_And_Laser
```

```
# Probe offsets either manually entered or from active probe
```

```
Probe_Offsets_Valid:Yes
```

```
Probe_Offset:0.0000,0.0000,-205.0700
```

```
Start_Point:1155.9370,2119.2178,-1168.3508
```

```
Measurement_Axis:-0.444749590,-0.815374248,0.370624658
```

```
Measurement_Type:Scale
```

```
#
```

```
Point:<direction/index>,<nominal_distance>,<actual_distance>,<laser_value>,<X,Y,Z>,<deviation>
```

```
# Value of <actual_distance> is deviation parallel to measurement axis
```

```
# Value of <deviation> is zero offset and slope compensated if measurement type is straightness
```

```
Measurement_Begin:
```

```
Description:SQ2
```

```
Point:0,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
```

```
Point:1,500.0000,500.0000,500.0100,933.5622,1711.5307,-983.0385,-0.0100
```

```
Point:2,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
```

```
Point:3,500.0000,500.0000,500.0100,933.5622,1711.5307,-983.0385,-0.0100
```

```
Point:4,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
```

```
Point:5,500.0000,500.0000,500.0100,933.5622,1711.5307,-983.0385,-0.0100
```

```
Point:6,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
```

```
Point:7,1000.0000,1000.0000,1000.0200,711.1874,1303.8436,-797.7261,-0.0200
```

```
Point:8,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
```

```
Point:9,1000.0000,1000.0000,1000.0200,711.1874,1303.8436,-797.7261,-0.0200
```

```
Point:10,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
```

# Squareness Calculator Users Guide

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```
Point:11,1000.0000,1000.0000,1000.0200,711.1874,1303.8436,-797.7261,-0.0200
Point:12,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:13,1500.0000,1500.0000,1500.0300,488.8126,896.1564,-612.4138,-0.0300
Point:14,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:15,1500.0000,1500.0000,1500.0300,488.8126,896.1564,-612.4138,-0.0300
Point:16,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:17,1500.0000,1500.0000,1500.0300,488.8126,896.1564,-612.4138,-0.0300
Point:18,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:19,2000.0000,2000.0000,2000.0400,266.4378,488.4693,-427.1015,-0.0400
Point:20,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:21,2000.0000,2000.0000,2000.0400,266.4378,488.4693,-427.1015,-0.0400
Point:22,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:23,2000.0000,2000.0000,2000.0400,266.4378,488.4693,-427.1015,-0.0400
Point:24,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:25,2500.0000,2500.0000,2500.0500,44.0630,80.7822,-241.7891,-0.0500
Point:26,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:27,2500.0000,2500.0000,2500.0500,44.0630,80.7822,-241.7891,-0.0500
Point:28,0.0000,0.0000,0.0000,1155.9370,2119.2178,-1168.3508,0.0000
Point:29,2500.0000,2500.0000,2500.0500,44.0630,80.7822,-241.7891,-0.0500
```

Measurement\_End:

## Example of MeasureDirect scale data with the laser:

PMove\_Raw\_Measurement:Version=1:Type=Machine\_And\_Laser

# Probe offsets either manually entered or from active probe

Probe\_Offsets\_Valid:Yes

Probe\_Offset:0.0000,0.0000,-205.0700

Start\_Point:44.0630,2119.2178,-1168.3508

Measurement\_Axis:0.444749590,-0.815374248,0.370624658

Measurement\_Type:Scale

#

Point:<direction/index>,<nominal\_distance>,<actual\_distance>,<laser\_value>,<X,Y,Z>,<deviation>

# Value of <actual\_distance> is deviation parallel to measurement axis

# Value of <deviation> is zero offset and slope compensated if measurement type is straightness

Measurement\_Begin:

Description:SQ3

```
Point:0,0.0000,0.0000,0.0000,44.0630,2119.2178,-1168.3508,0.0000
Point:0,250.0000,250.0000,250.0050,155.2504,1915.3742,-1075.6946,-0.0050
Point:0,500.0000,500.0000,500.0100,266.4378,1711.5307,-983.0385,-0.0100
Point:0,750.0000,750.0000,750.0150,377.6252,1507.6871,-890.3823,-0.0150
Point:0,1000.0000,1000.0000,1000.0200,488.8126,1303.8436,-797.7261,-0.0200
Point:0,1250.0000,1250.0000,1250.0250,600.0000,1100.0000,-705.0700,-0.0250
Point:0,1500.0000,1500.0000,1500.0300,711.1874,896.1564,-612.4138,-0.0300
Point:0,1750.0000,1750.0000,1750.0350,822.3748,692.3129,-519.7577,-0.0350
Point:0,2000.0000,2000.0000,2000.0400,933.5622,488.4693,-427.1015,-0.0400
Point:0,2250.0000,2250.0000,2250.0450,1044.7496,284.6257,-334.4453,-0.0450
Point:0,2500.0000,2500.0000,2500.0500,1155.9370,80.7822,-241.7892,-0.0500
```

Measurement\_End:

# Squareness Calculator Users Guide

---

## Comments:

- First line must be *Pmove\_Raw\_Measurement:Version=1:Type=Machine\_And\_Laser* or *B89.4.10360\_Raw\_Measurement:Version=1:Type=Machine\_And\_Laser*.
- *Start\_Point* defines the zero position of the measurement.
- *Measurement\_Axis* defines the direction of the measurement.
- Measurements must be surrounded by separate *Measurement\_Begin:* and *Measurement\_End:* entries or the measurement data will be ignored.
- Description defines the name of the measurement. The imported data will use this as part of the name for the length entry.
- Comment lines begin with the hash symbol (#).

## Data Entries:

Point:<direction/

index>,<nominal\_distance>,<actual\_distance>,<laser\_value>,<X,Y,Z>,<deviation>

## Where:

<direction/index> = zero based point index or direction (0=forward, 1=reversed)

<nominal\_distance> = nominal distance of the measurement

<actual\_distance> = actual distance the machine moved parallel to the measurement axis.

<laser\_value> = data entered from the laser.

<XYZ> = XYZ position of the point

<deviation> = calculated deviation between the laser and the machine.

## BnS Service Utilities Results File

This format is generated by the BnS service utilities when measuring ballbar or step gauges. The format of the file is XML and contains entries beyond the measurement of ballbar or step gauges and is too involved to be described in this document.

*This format is outside of the control of SCI and may be changed by BnS in the future. The contents of the file is not ideal and various problems noticed with the data contents are not taken into account when calculating squareness corrections. Ballbar and stepgauge data is the only information read from this file.*

## Ballbar 10360 Version 1 Format

This format is used for 10360-2 measurements on a CMM with a 10360 ballbar consisting of five lengths measured 3 times. When measured along body diagonals three lengths are extracted from the six spheres positions and averaged to a single set of results.

*It may seem odd to extract three measured lengths when five lengths are known but for squareness updates the goal was to have symmetrical lengths from a central position. In theory both will work but in practice working from a central position shouldn't result in a bias from either end of the 10360 ballbar.*

## Example:

```
B89.4.10360_Raw_Measurement:Version=1:Type=BallBar_10360
```

```
Alignment_Begin:
```

```
X_Axis:-0.425864069,0.816239457,0.390375388
```



# Squareness Calculator Users Guide

---

Y\_Axis:-0.577350269,-0.577350269,0.577350269  
Z\_Axis:0.696639406,0.020489399,0.717128805  
Translation:802.8781,604.3404,-1114.6657  
Alignment\_End:

Temperature\_Begin:  
X\_Scale:19.000  
Y\_Scale:20.000  
Z\_Scale:21.000  
Gauge:22.000  
Temperature\_End:

Probe\_Offset:-58.2600,58.2600,-160.9421  
Probe\_Vector:-0.500000000000,0.500000000000,-0.707106781187

Scales\_Begin:  
X\_Expansion\_Coefficient:10.0  
Y\_Expansion\_Coefficient:10.0  
Z\_Expansion\_Coefficient:10.0  
Scales\_End:

Equipment\_Identification:90210

Measurement\_Begin:  
Description:Position 1  
Sphere\_Zero\_Offset:0

Sphere:A,0,0,-0.00077,0.00123,-0.00225,25.00359,0.00597  
Sphere:B,0,0,200.00018,0.00010,0.00009,24.99713,0.00670  
Sphere:A,0,1,-0.00217,0.00223,-0.00006,25.00169,0.00589  
Sphere:B,0,1,200.00153,0.00051,-0.00313,24.99637,0.00884  
Sphere:A,0,2,-0.00067,-0.00194,-0.00371,25.00099,0.00510  
Sphere:B,0,2,200.00209,0.00101,-0.00378,25.00224,0.00492  
Sphere:A,1,0,0.00119,0.00215,-0.00506,25.00046,0.00197  
Sphere:B,1,0,299.99752,0.00173,-0.00398,25.00150,0.00409  
Sphere:A,1,1,-0.00227,0.00107,-0.00358,25.00150,0.00843  
Sphere:B,1,1,299.99953,0.00054,0.00275,25.00146,0.00836  
Sphere:A,1,2,-0.00182,-0.00091,0.00127,24.99686,0.00505  
Sphere:B,1,2,300.00001,-0.00207,0.00347,24.99819,0.00407  
Sphere:A,2,0,0.00238,-0.00013,-0.00154,24.99787,0.00648  
Sphere:B,2,0,499.99858,0.00162,0.00549,24.99890,0.00603  
Sphere:A,2,1,0.00196,-0.00133,-0.00103,25.00225,0.00759  
Sphere:B,2,1,499.99878,-0.00030,0.00237,25.00036,0.00505  
Sphere:A,2,2,-0.00045,0.00358,0.00346,24.99814,0.00448  
Sphere:B,2,2,500.00112,0.00029,-0.00291,24.99910,0.00621  
Sphere:A,3,0,-0.00178,-0.00023,0.00079,24.99983,0.00771  
Sphere:B,3,0,599.99927,0.00170,0.00157,25.00227,0.00780  
Sphere:A,3,1,-0.00094,0.00152,-0.00315,25.00091,0.00617  
Sphere:B,3,1,599.99900,0.00152,0.00537,24.99868,0.00266  
Sphere:A,3,2,-0.00113,-0.00085,0.00553,24.99860,0.00670  
Sphere:B,3,2,599.99941,0.00107,-0.00172,24.99926,0.00656  
Sphere:A,4,0,0.00170,0.00071,-0.00221,25.00143,0.00450  
Sphere:B,4,0,800.00112,0.00104,0.00118,24.99817,0.00803  
Sphere:A,4,1,0.00098,0.00090,0.00036,24.99887,0.00806  
Sphere:B,4,1,799.99920,0.00076,-0.00143,25.00008,0.00835  
Sphere:A,4,2,0.00220,0.00184,0.00226,24.99866,0.00639  
Sphere:B,4,2,800.00233,-0.00186,0.00417,24.99874,0.00540  
Measurement\_End:

# Squareness Calculator Users Guide

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## Comments:

- First line must be *B89.4.10360\_Raw\_Measurement:Version=1:Type=BallBar\_10360*
- Alignment section indicates the orientation of the measurement with X along the gauge.
- Measurements must be surrounded by separate *Measurement\_Begin:* and *Measurement\_End:* entries or the measurement data entries will be ignored.
- Comment lines begin with the hash symbol (#).

## Data Entries:

Sphere: <A/B>,<run>,<step>,X,Y,Z,DM,F

## Where:

<A/B> = measurement of sphere A or sphere B

<run> = zero based length counter

<step> = zero based measurement counter

<XYZ> = XYZ position of each point along the measurement line

<DM> = Diameter of the sphere measurement

<F> = Form error of the sphere measurement

*The entries for the Equipment\_Identification, Probe\_Offset, Probe\_Vector, and Sphere\_Zero\_Offset are currently ignored by the Squareness Calculator utility. The nominal length is the measured length rounded to the nearest mm. For best results the nominal length of each individual length should be updated to the proper value particularly if the measurement diagonals differ in length or there is poor symmetry in the positions.*

## Suggestions for Manual Data Entry

When measuring body diagonals of a machine a reasonable IJK value can be entered by simply inputting 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.

Name:	<input type="text" value="Length 1"/>		
Nominal Length:	<input type="text" value="1000.0000"/>		
Actual Length:	<input type="text" value="1000.020"/>		
	<input type="text" value="X"/>	<input type="text" value="Y"/>	<input type="text" value="Z"/>
Position:	<input type="text" value="599.903"/>	<input type="text" value="1124.932"/>	<input type="text" value="-600.000"/>
	<input type="text" value="I"/>	<input type="text" value="J"/>	<input type="text" value="K"/>
Direction:	<input type="text" value="1200"/>	<input type="text" value="2200"/>	<input type="text" value="1000"/>
<input type="button" value="Edit Axis Points"/>		<input type="button" value="Apply"/> <input type="button" value="Reset"/>	

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

Name:	<input type="text" value="Length 1"/>		
Nominal Length:	<input type="text" value="1000.0000"/>		
Actual Length:	<input type="text" value="1000.020"/>		
	<input type="text" value="X"/>	<input type="text" value="Y"/>	<input type="text" value="Z"/>
Position:	<input type="text" value="599.903"/>	<input type="text" value="1124.932"/>	<input type="text" value="-600.000"/>
	<input type="text" value="I"/>	<input type="text" value="J"/>	<input type="text" value="K"/>
Direction:	<input type="text" value="0.44474959"/>	<input type="text" value="0.81537425"/>	<input type="text" value="0.37062466"/>
<input type="button" value="Edit Axis Points"/>		<input type="button" value="Apply"/> <input type="button" value="Reset"/>	

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.

## Squareness Calculator Users Guide

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*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 calculation error. The *Squareness Calculator* utility can be used to estimate the amount of error from using approximations of the measurement positions and directions. Two examples were chosen where the first was a basic XY squareness from two ballbar measurements and the second from using four 3D diagonal ballbar positions.

#### Squareness From Two B89.4.1 Ballbar Measurements

The measurement of one squareness projection plane can be done with only two ballbar 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. Illustration 9 and illustration 10 would be a practical measurement example of a measurement for the XY squareness on a CMM where it would be practically impossible to have a set of measurements in the exact XY plane of the coordinate system of the CMM.

*Since the ballbar measurements are not flat in 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.*

# Squareness Calculator Users Guide

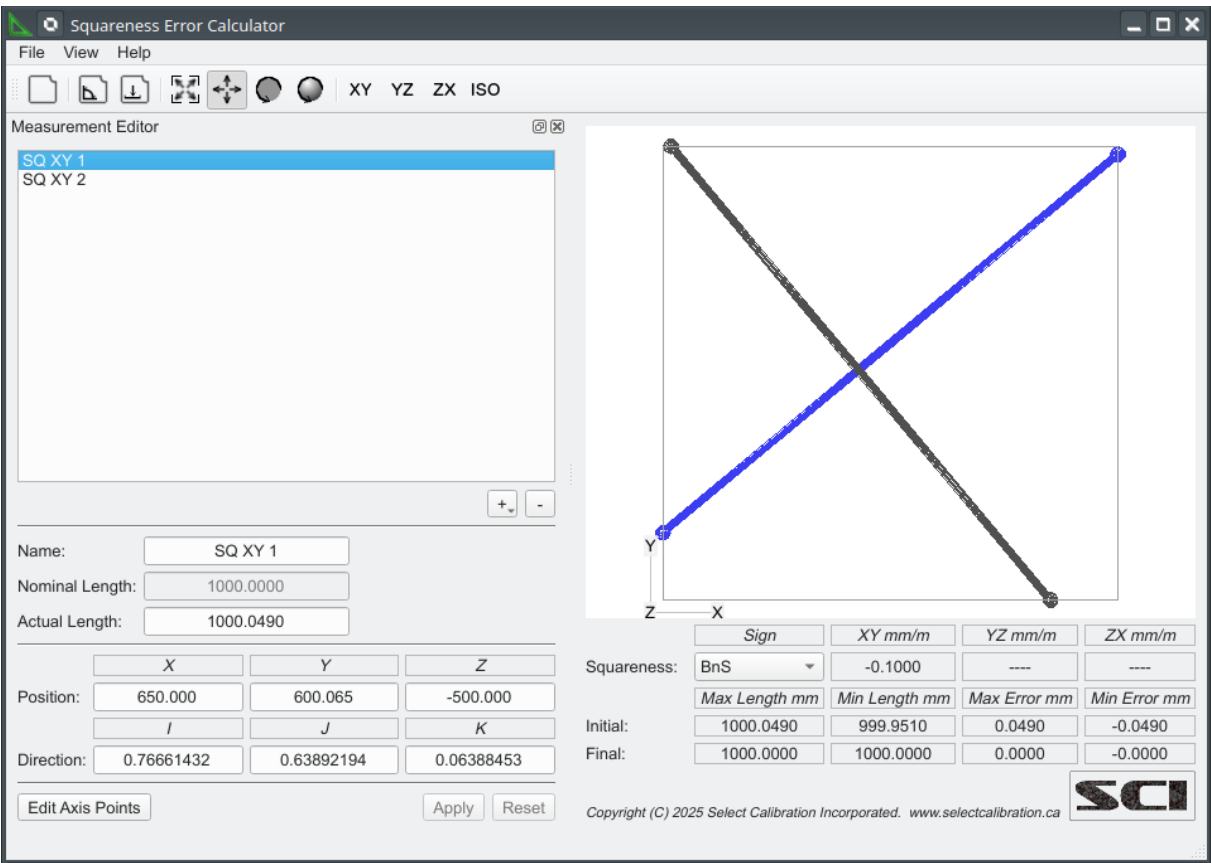


Illustration 8: Measurement of XY squareness example.



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

# Squareness Calculator Users Guide

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.

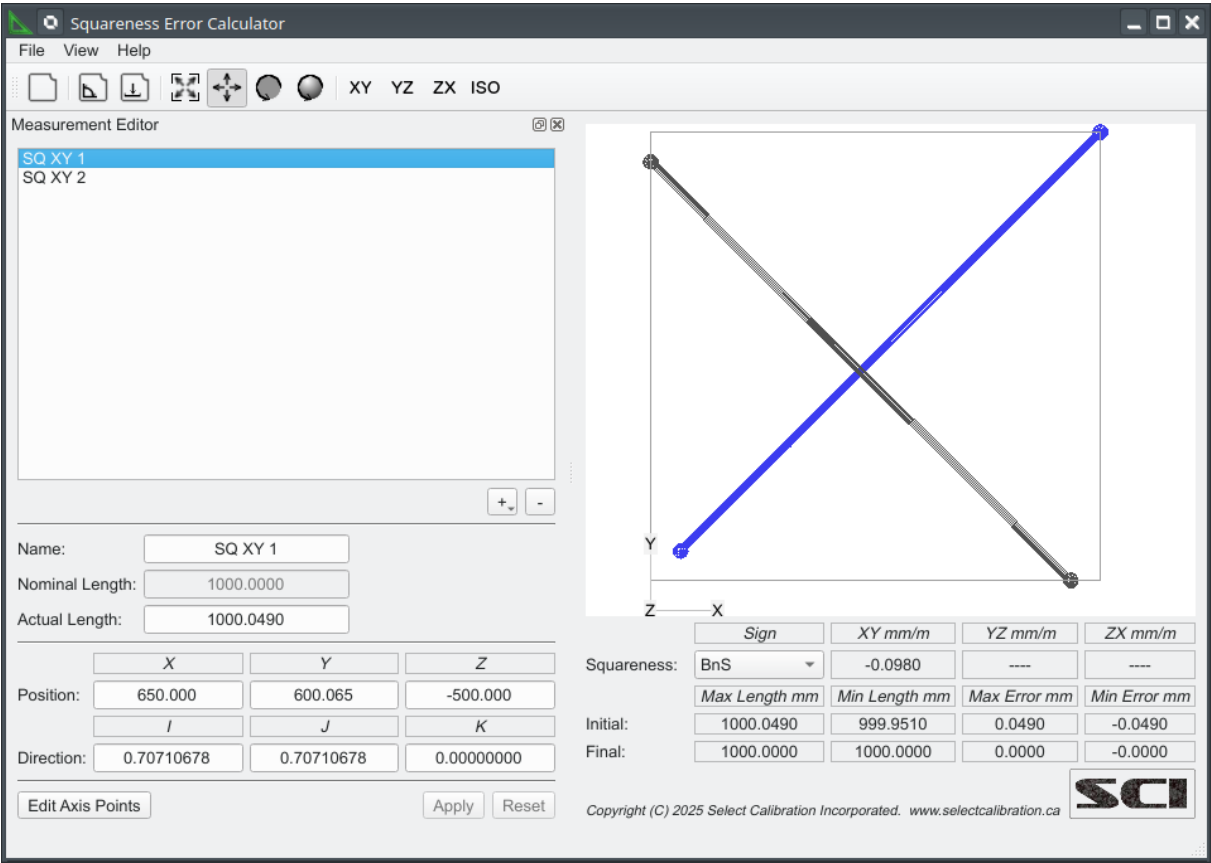


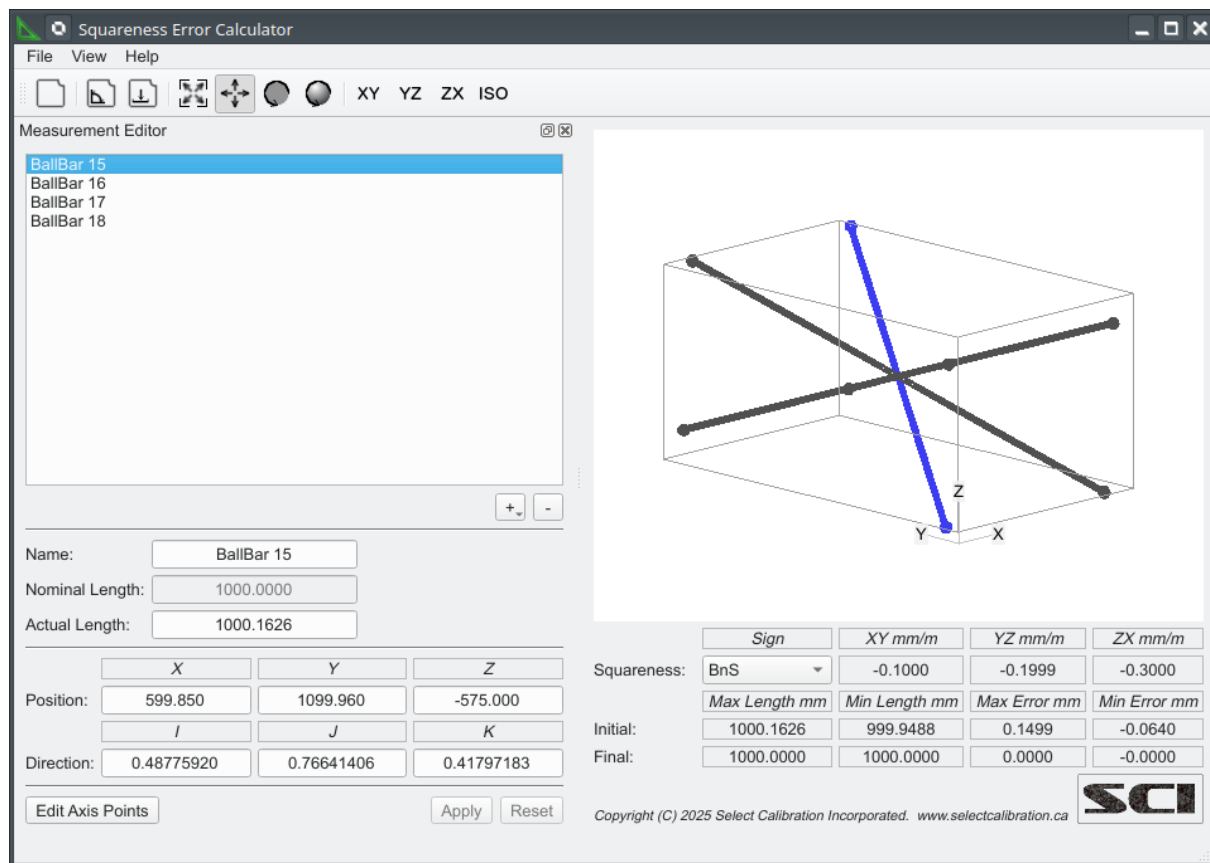
Illustration 11: Measurement result using a nominal measurement axis.

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 B89.4.1 Ballbar Measurements

The XY, YZ, and ZX squareness errors can be extracted from four 3D B89.4.1 ballbar 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.

# Squareness Calculator Users Guide



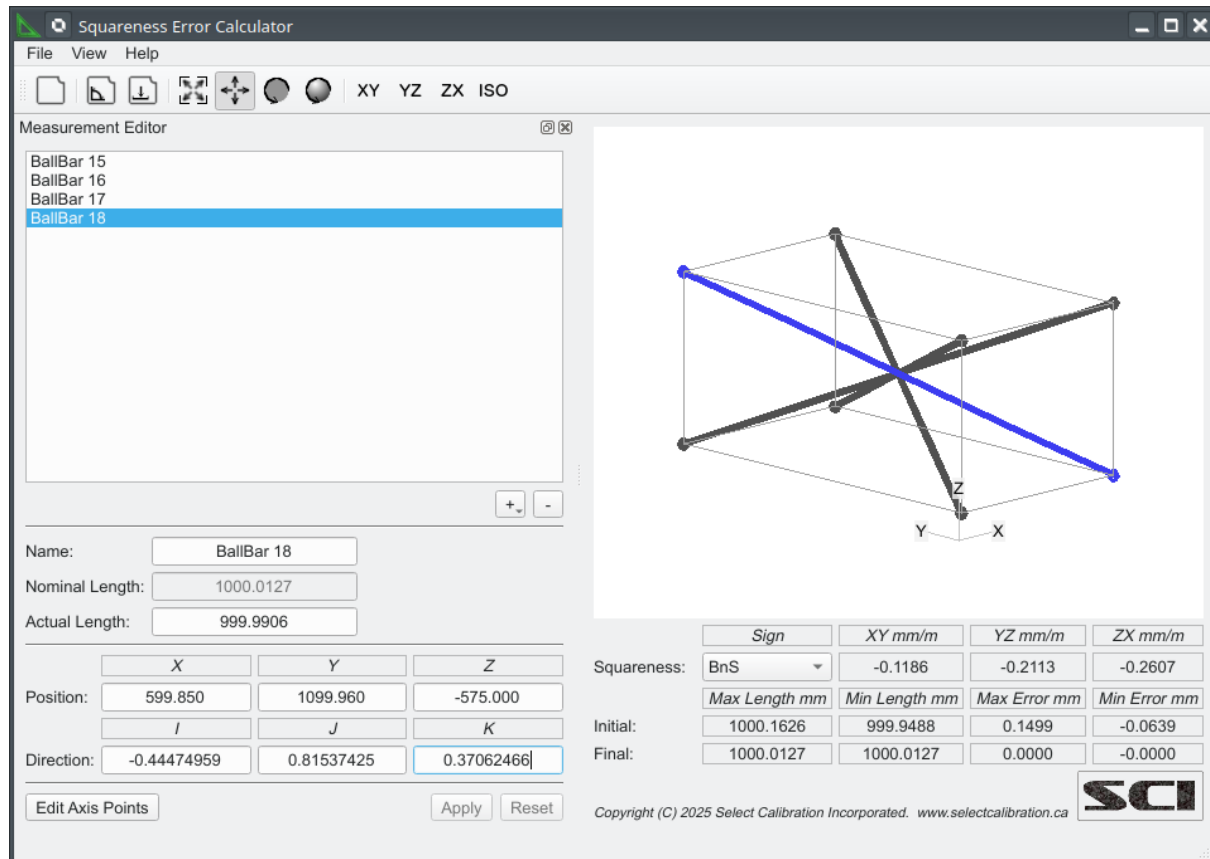
Measurement	Item	Value
BallBar 15	Length	1000.1626 mm
	Nominal Axis IJK	0.44474959, 0.81537425, 0.37062466
	Angle from Nominal Axis	4.6 degrees

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

## Squareness Calculator Users Guide

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.

### Squareness From Four 3D Diagonal 10360 Ballbar Measurements

The XY, YZ, and ZX squareness errors can be extracted from four volume positions of the 10360 ballbar 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.

# Squareness Calculator Users Guide

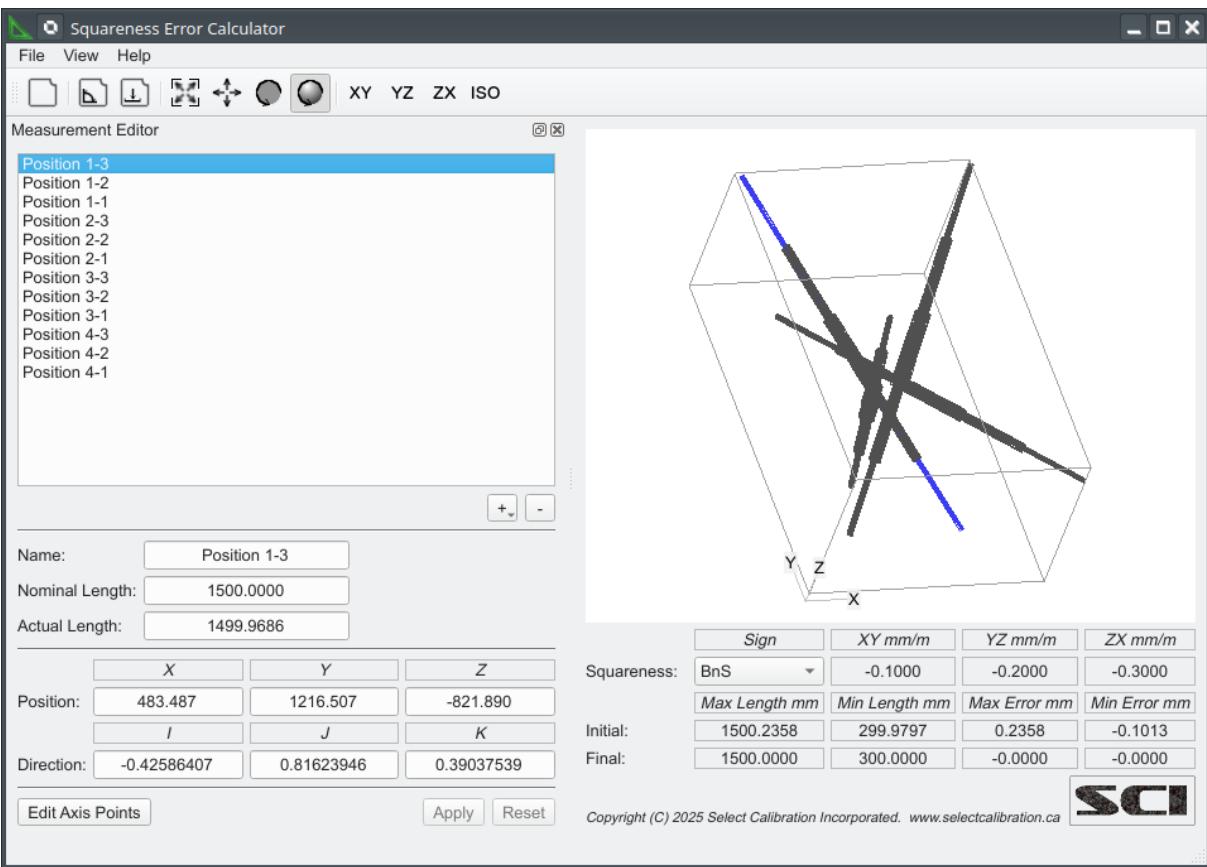


Illustration 12: 10360 ballbar measurement showing variations in position and orientation.

For each position three lengths are extracted and show as separate entries using the position name for the first part of the description.

The orientation and position of each of the four positions is more realistic for something that would be actually measured on a CMM. Extracting the squareness errors from four body diagonals is more involved then would be necessary when using a 2D B89.4.1 ballbar measurement and is even harder when dealing with variations in position and orientation. Illustration 12 shows one example of something that would be more realistic for an actual measurement on a CMM.

*The results from the four body diagonals as shown in illustration 12 solve to the expected 100, 200, and 300 um/m corrections.*



## Squareness Calculator Users Guide

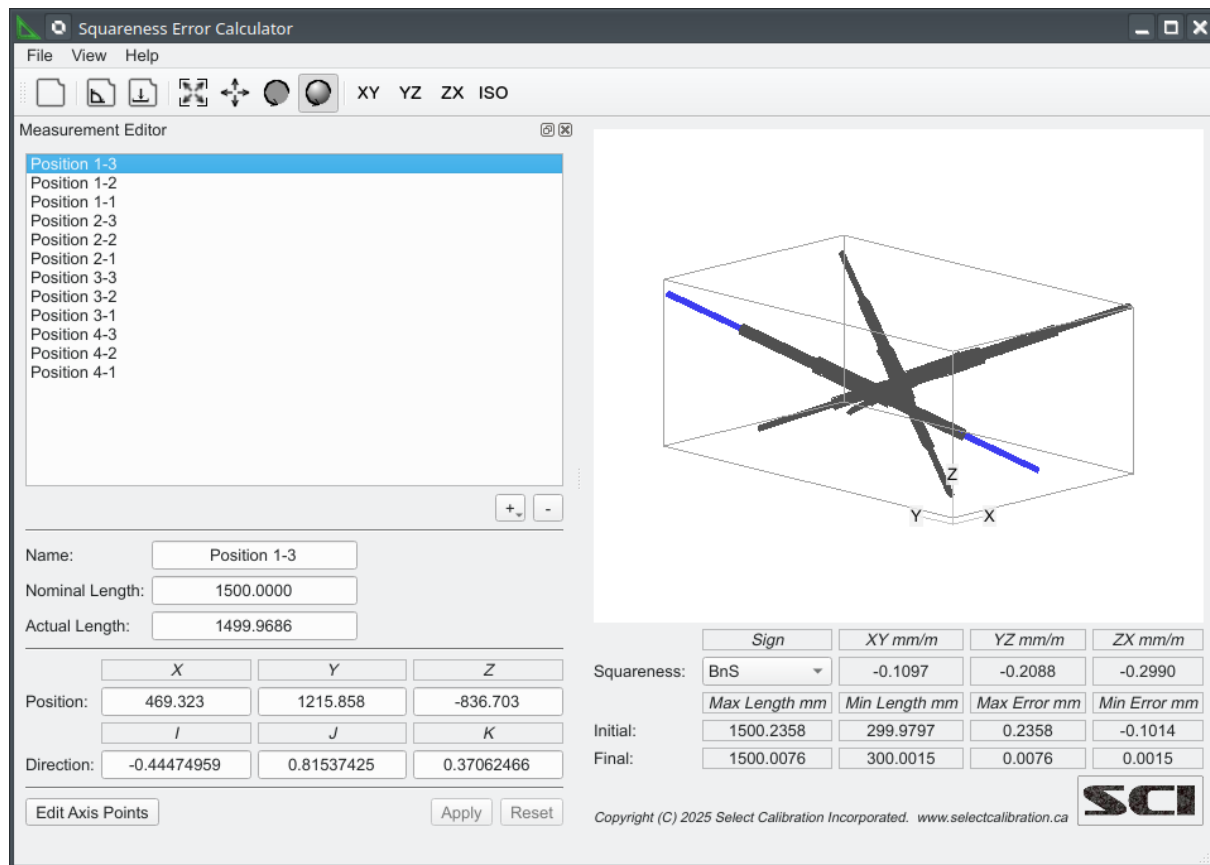


Illustration 13: Results from four body diagonals ignoring actual measured axis.

The measurement data from illustration 12 was used with only the measurement directions updated to nominal directions based on the size of the machine. The result, as shown in illustration 13 shows an error from the expected corrections of almost 10  $\mu\text{m}/\text{m}$  for some corrections (9.7% error of the ideal XY squareness correction).

Using Position 1 as an example the original measurement direction (X\_Axis data) is:

```
Alignment_Begin:  
X_Axis:-0.425864069,0.816239457,0.390375388  
Y_Axis:-0.577350269,-0.577350269,0.577350269  
Z_Axis:0.696639406,0.020489399,0.717128805  
Translation:802.8781,604.3404,-1114.6657  
Alignment_End:
```

which was updated to the nominal measurement direction of:

```
Alignment_Begin:  
X_Axis:-0.444749590,0.815374248,0.370624658  
Y_Axis:-0.577350269,-0.577350269,0.577350269  
Z_Axis:0.684736788,0.042796049,0.727532837  
Translation:802.8781,604.3404,-1114.6657  
Alignment_End:
```

The difference between the two measurement lines is approximately 1.6 degrees and even with this small angle there is a noticeable difference in the calculated squareness corrections.

## Squareness Calculator Users Guide

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### Revision History

<i>Date</i>	<i>Version</i>	<i>Changes</i>
Jan 26, 2020	1.0	New Program
Mar 30, 2020	1.1	[bug fix] Nominal ballbar length not visually updated. Added Renishaw sign option. Changed selection color from green to blue.
Apr 16, 2020	1.2	[bug fix] Measurement statistics not always updated with new data.
Jan 4, 2012	1.3	Added support for stepgauge square measurement files.
Nov 20, 2021	1.4	[bug fix] Squareness sign for LK YZ reversed. Changed position and background for CSY axis labels.
Jan 20, 2023	1.5	Added support for MeasureDirect laser files.
Jan 6, 2024	2.0	Added ability to import BnS ballbar and stepgauge data.
Jan 9, 2024	2.1	[bug fix] Missing menu option for importing BnS data. Added SCI logo.
May 4, 2025	3.0	[bug fix] Probe offset index wrong for BallBar_V2 data. Added option to import Ballbar 10360 data.