Comparison ISO 10360-2 to ASME B89.4.1

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Comparison ISO 10360-2:2009 to ASME B89.4.1:1997

Introduction

The purpose of this article is to compare the capability of the ISO/IEC 10360-2:2009 (or the virtually identical standard ASME B89.4.10360-2:2008) and ASME B89.4.1:1997 standards for testing the performance of a coordinate measuring machine. This article doesn't address the measurement details of either standard outside of the parts that affect the comparison between the two standards. The capability of either standard to reliably test the performance of a coordinate measuring machine is of interest.

The results of running tests defined by either standard are not significant other than to compare against a base line provided by the manufacturer to decide if the machine is acceptable or not. Unlike equipment that has a dedicated measurement function a CMM is a universal measurement tool therefore the measurements done to test the machine are usually not be the same as the customers use of the equipment. Proving the machine can measure X does not guarantee the capability to measure Y.

The Renishaw Machine Checking Gauge is included in the comparison tests as a point of reference. This gauge is ideal for CMM interim checking due to its speed and ease of use so therefore a comparative test using this gauge to established standards seemed appropriate.

Overview Of Standards

The two common methods used for performance testing of CMM's are very different. The ball bar standard uses an uncalibrated length and is essentially a length repeatability throughout the measurement volume of the CMM. The 10360 standard is the measurement of a calibrated length throughout the volume of the machine.

The ASME B89.4.1 ball bar standard is generally confined to North America where the 10360 standard has its origins in Europe and is derived from other standards that were based on the measurement of certified length standards.

ISO/IEC 10360-2 Performance Test

The ISO/IEC 10360-2 length test is done by measuring five lengths along nine specified measurement lines (seven measurement lines for E0 and two measurement lines for E150). There are five measurement lengths along any measurement line repeated three times for a total of 15 unique results. The largest error from the 15 measurement lengths is the reported measurement value for that particular measurement line. For the nine measurement positions a total of 135 length measurements are collected (105 measurements for E0 and 30 measurements for E150).

The specifications for the ISO/IEC 10360-2 test are length dependent and usually expressed as a formula. An example of a typical ISO/IEC 10360-2 specification is shown below:

$E_l\, MPE = 0.003 + 0.004\, L$ where L is length in meters.

The specifications is a +/- tolerance. Using the example specification from above the tolerance would be +/- 0.007 mm for a measurement length of one meter.

ASME B89.4.1 Performance Test

The ball bar is the primary equipment used to test the volume of the machine for the ASME B89.4.1 standard. This length of the ball bar is usually uncalibrated so the test is to verify the measurement of length is repeatable throughout the volume of the machine.

The axis scales are calibrated as a separate test (Linear Displacement Accuracy) using a calibrated artifact such as a step gauge or laser. Once the axis scales have been set to measure properly the ball bar is used as a kind of transfer standard to ensure the measurement of length parallel to any axis will repeat when measuring anywhere in the volume of the coordinate measuring machine.

The specification for the ASME B89.4.1 ball bar test is the maximum range of results from all measurements. The specification usually is shown as a single value with an associated nominal ball bar length but a full length dependent formula has been used in some cases.

$$E_{limit}=0.007/1000$$

The longest ball bar length that can be practically used must be slightly shorter than the shortest axis of the CMM (typically 100 mm shorter than the shortest axis). To address this limitation different patterns of ball bar tests are used for different configurations of CMM axis dimensions.

Performance testing of a CMM using an uncalibrated ball bar, without testing the axis scales, does not follow the intent of the ASME B89.4.1:1997 standard.

Testing Criteria

When comparing the two performance standards the following items are considered important:

- Sensitivity of the performance test.
- Sensitivity to all common CMM errors.

A performance test that reports the largest measurement error with the smallest machine error(s) is preferred. The primary purpose of performance testing is to identify problems with the coordinate measuring machine so tests that are more sensitive to errors are clearly preferred.

The performance test must be sensitive to all errors of the CMM. If the performance test cannot detect specific types of machine errors then these errors may actually exist even though the performance test does not reveal any problems. In all cases limitations of the standard can be supplemented by additional tests but this requires someone to recognize that additional measurements are necessary.

In addition to the listed criteria it should also be noted that one desirable feature is speed and simplicity. The measurement of the ISO/IEC 10360-2:2009 pattern has fewer measurement lines as compared to the ASME B89.4.1 ball bar standard but the ball bar measurements are easier to perform. The MCG gauge is by far the easiest of the three methods.

Test Procedure

The evaluation was done using a simulated coordinate measuring machine measuring artifacts meeting the requirements of ASME B89.4.1:1997 and ISO/IEC 10360-2:2009. Once the machine was defined with specific errors each set of artifacts were evaluated and the results written to a file. The three sets of artifacts were for all ASME B89.4.1 ball bar positions, all ISO/IEC 10360-2 El measurements, and a single Machine Checking Gauge measurement at measurement volume center.

The parameters manipulated for the comparison tests are RXX, RXY, RXZ, RYX, RYY, RYZ, RZX, RZY, RZZ, QXY, QYZ, QZX. Each parameter was activated individually and combined with every other combination of parameters for a total of 4095 sets of measurements ($2^{12}-1$). For each combination of machine errors a summary of the measurement results were written to a file in a format as shown below:

```
                                        |                Ball Bar                |
 Active Compensation Parameters             Min Error  Max Error  Min Len    Max Len
--------------------------------------------------------------------------------------------
...
|RXX|RXY|RXZ|RYX|                       |  -0.002000,  0.002581,  999.9980, 1000.0026
|RXX|RYZ|RZX|RZY|RZZ|QZX|               |  -0.000911,  0.002581,  999.9991, 1000.0026
...
```

The file has four possible groups of measurement listed side by side on a single line of text (only some of the results are shown due to the width of the output file). The active compensation parameters that produced the results are shown in the first column of the data.

Scale errors were not included in the simulated CMM. This would put an unfair advantage on the ISO/IEC 10360-2 performance test when only comparing to a ball bar measurement pattern. Straightness errors are indirectly included as a product of the angular errors and probe offsets.

CMM

The configuration of the CMM will be a factor in the results. The most common configuration of a coordinate measuring machine is one where one axis is twice the length of the other two. The measurement volume used for testing was chosen to be 1000 x 2000 x 1000 mm for the three levels or errors. A second measurement volume of 1000 x 1000 x 1000 mm was added for additional tests to see what effect the configuration of the measurement volume has on the results.

Standards

The measurement positions and requirements follow the associated standard to the letter. For the

ASME B89.4.1 ball bar test there are 34 positions of which 30 follow the recommended 2.1.1 pattern and 4 are used for probe roll measurements with a probe offset of 150 mm from the vertical axis of the CMM. The length of the ball bar is equal to the shortest length of the three axis.

The measurement when running the ISO/IEC 10360-2 test are the required positions for the E0 and E150 measurement lines. The five measurement lengths begin at the one end of the measurement line and are broken up into lengths of 20%, 40%, 60%, 80%, and 100% of the total length.

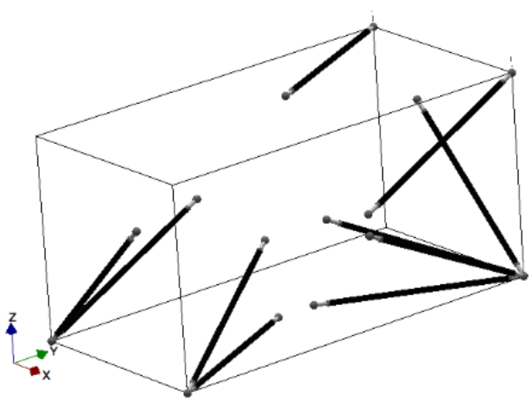

Illustration 1: ball bar positions 1 - 10

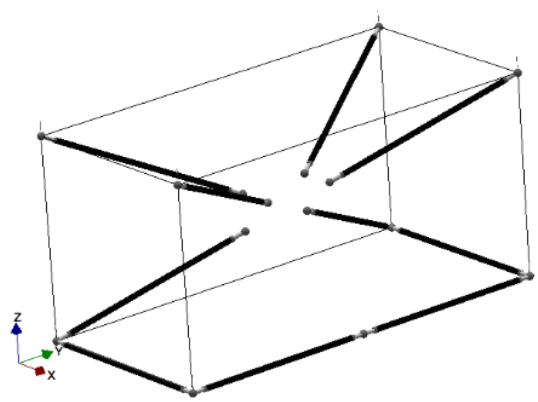

Illustration 2: ball bar positions 11 - 20

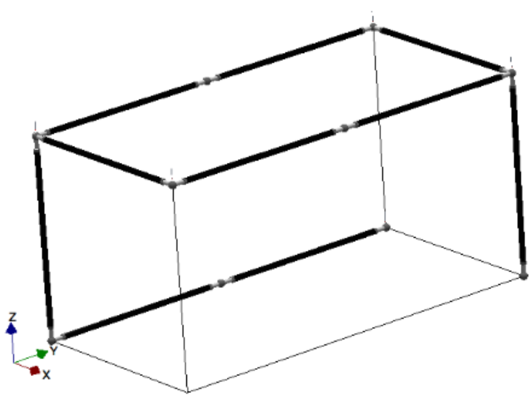

Illustration 3: ball bar positions 21 – 30. ball bar positions 1 – 30 use a basic probe offset.

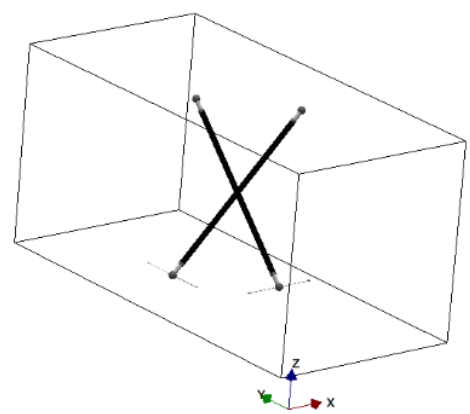

Illustration 4: ball bar positions 31 – 34 for probe roll. Each position is measured twice using an offset probe.

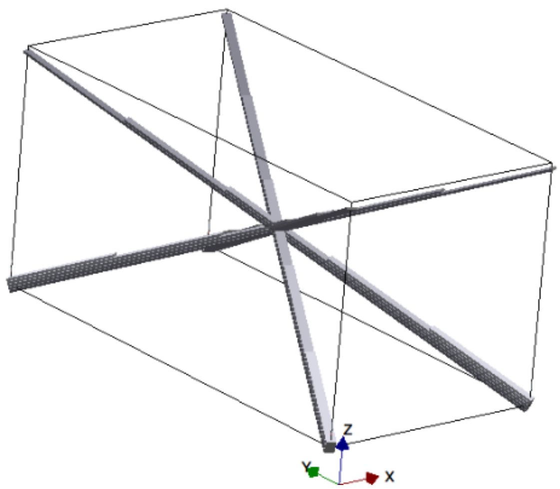

Illustration 5: E0 measurement positions 1 - 4

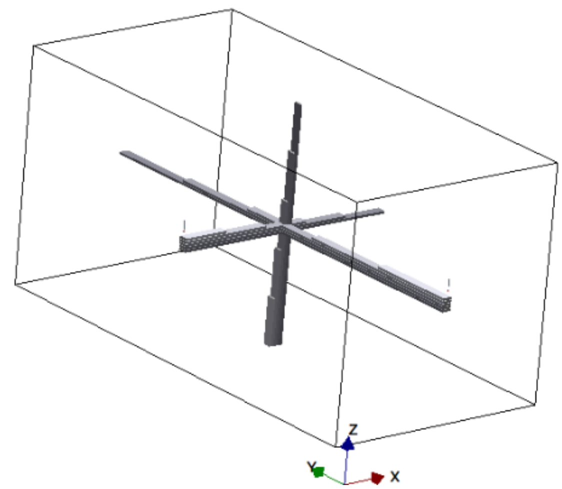

Illustration 6: E0 measurement positions 5 - 7

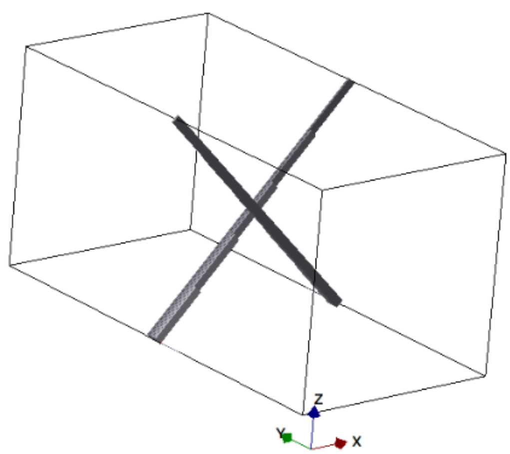

Illustration 7: E150 measurement positions D1 – D2 measured with offset probe.

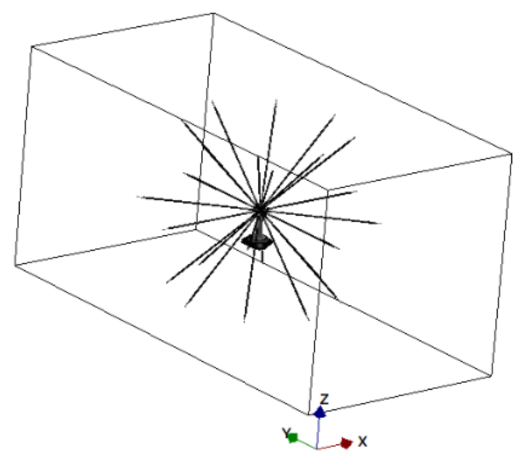

Illustration 8: Renishaw MCG standard 24 position pattern from -45 to 45 degree elevation.

The Renishaw Machine Checking Gauge is not an artifact used by either the ASME B89.4.1 or the ISO/IEC 10360-2 standard nor does the measurement follow recommendations of either standard. It is an effective tool for interim checks of the machine and was included as part of the comparison tests. Illustration 8 shows a graphical representation of the MCG measurement in the volume of the test machine.

Probe Offset

The probe offset is minimal for all measurements except for the four ball bar positions used to detect probe roll error. The offset for both the probe roll ball bar tests and the E150 10360-2 measurements are 150 mm.

Measurement Equalization

In order to compare the results from the different tests it is necessary to have comparable results.

It was decided to normalize all measurement errors to a length of 1 meter. For the ball bar results no modification was required as the ball bar nominal length is 1 meter. The measurements of the ISO/IEC 10360-2 tests were converted to a comparable result by the following steps:

- Each measurement error at a specific measurement length is normalized to 1 meter.
- The largest normalized error is doubled to represent a bandwidth.

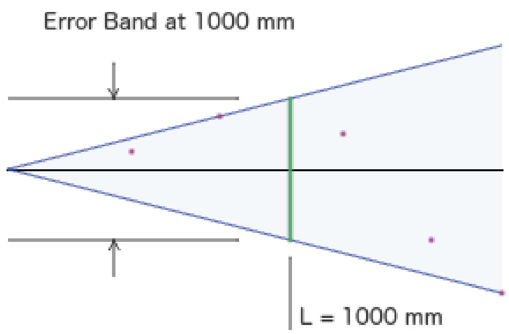

Illustration 9: Calculation of normalized measurement error bandwidth.

The Renishaw MCG results were also normalized to a length of 1 meter. For this gauge the maximum length of the test fork is no more than half the width of the machine. The MCG is not able to measure with the measurement fork parallel to the Z axis so usually the shorter of the machines X or Y axis defines the maximum length of the measurement fork. The equivalent ball bar length would be half of what was actually used so the error was simply doubled in order to produce a result comparable to 1 meter.

Testing Results

The results of the test are summarized in the following sections. The test uses every possible combination of machine errors from the twelve compensation parameters resulting in 4095 measurement results.

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Machine Error Minimal With Rectangular Measurement Volume

The test machine was defined with errors of 0.002 mm/m for all angular parameters and squareness. No scale error was included with this test. Two axis of the machine are 1000 mm and one axis is 2000 mm.

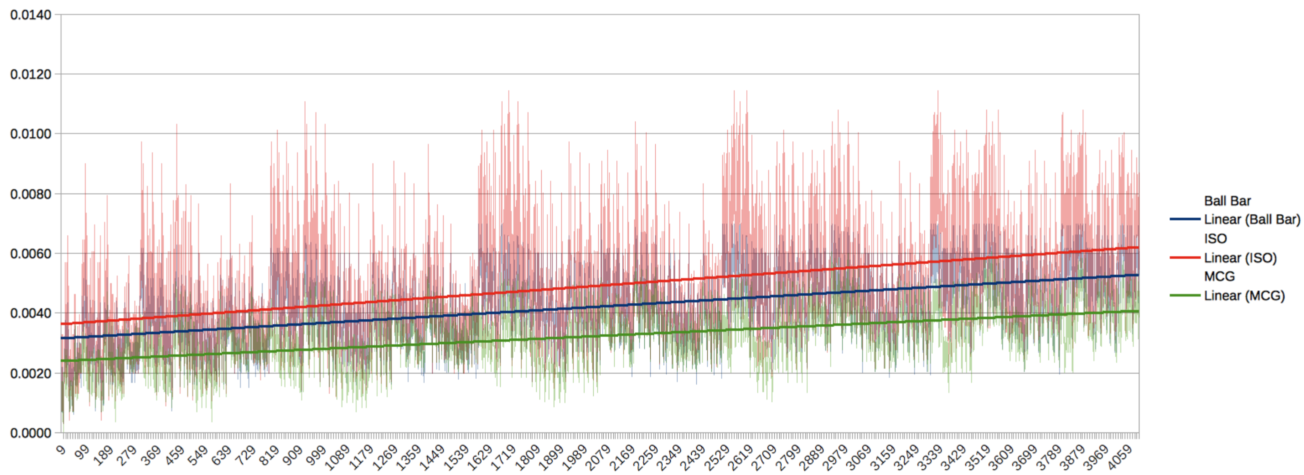

Illustration 10: Graph of ball bar, ISO 10360, and MCG measurement results over all test patterns using an error of 0.002 mm/m.

	ASME B89.4.1:1997	ISO/IEC 10360-2:2009	MCG
Minimum Error	0.0003	0.0003	0.0000
Maximum Error	0.0070	0.0115	0.0061
Average Error	0.0056	0.0068	0.0042
Average Error %	83.05%	100.00%	61.72%
Maximum Error %	61.09%	100.00%	52.89%

Moderate Machine Error With Rectangular Measurement Volume

The test machine was defined with errors of 0.005 mm/m for all angular parameters and squareness. No scale error was included with this test. Two axis of the machine are 1000 mm and one axis is 2000 mm.

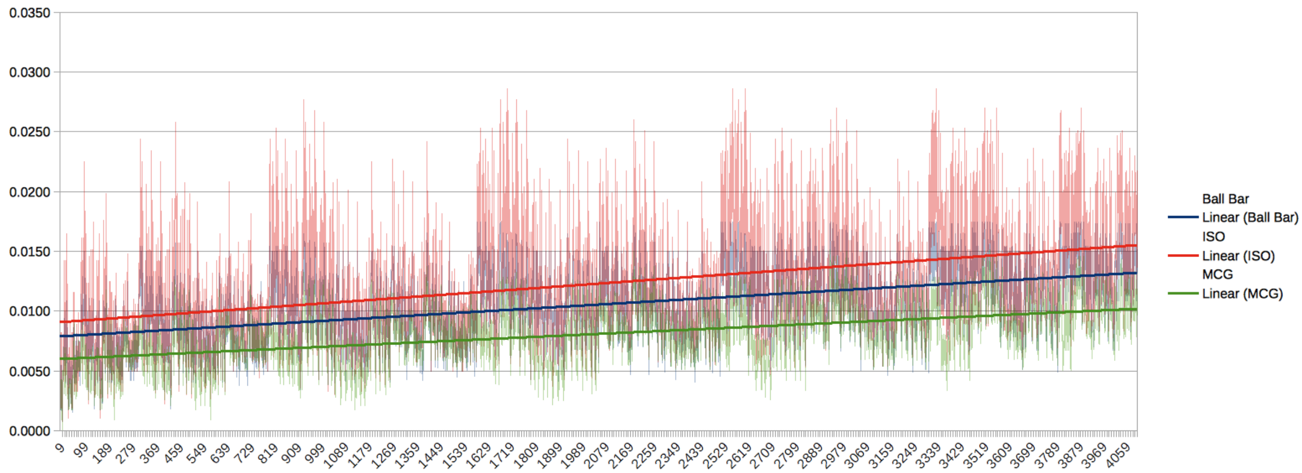

Illustration 11: Graph of ball bar, ISO 10360, and MCG measurement results over all test patterns using an error of 0.005 mm/m.

	ASME B89.4.1:1997	ISO/IEC 10360-2:2009	MCG
Minimum Error	0.0008	0.0007	0.0000
Maximum Error	0.0175	0.0286	0.0152
Average Error	0.0141	0.0170	0.0105
Average Error %	83.07%	100.00%	61.72%
Maximum Error %	61.10%	100.00%	52.91%

Large Machine Error With Rectangular Measurement Volume

The test machine was defined with errors of 0.010 mm/m for all angular parameters and squareness. No scale error was included with this test. Two axis of the machine are 1000 mm and one axis is 2000 mm.

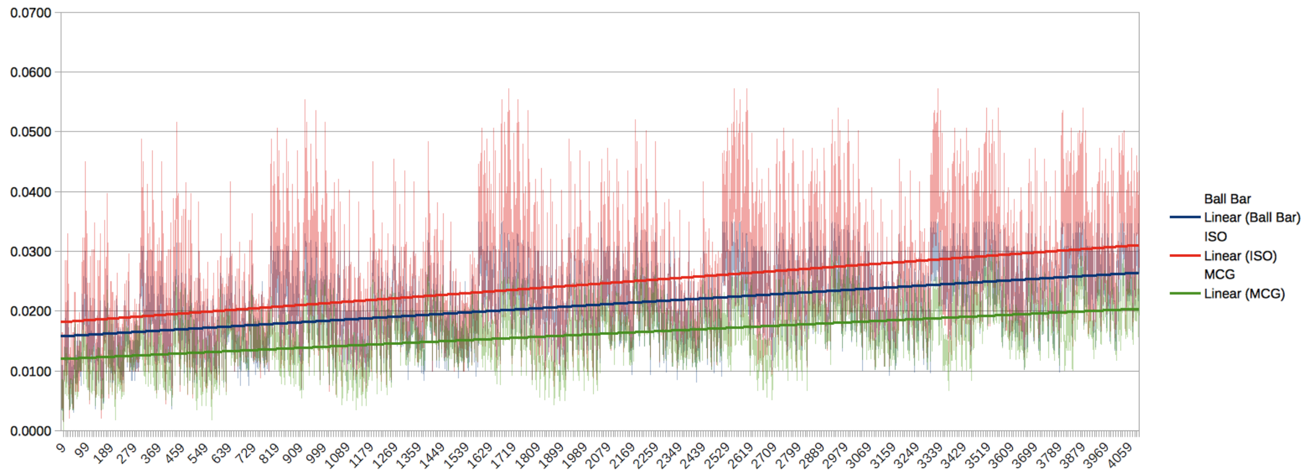

Illustration 12: Graph of ball bar, ISO 10360, and MCG measurement results over all test patterns using an error of 0.010 mm/m.

	ASME B89.4.1:1997	ISO/IEC 10360-2:2009	MCG
Minimum Error	0.0015	0.0015	0.0000
Maximum Error	0.0350	0.0573	0.0303
Average Error	0.0282	0.0339	0.0209
Average Error %	83.07%	100.00%	61.72%
Maximum Error %	61.09%	100.00%	52.91%

Large Machine Error With Cube Measurement Volume

The test machine was defined with errors of 0.010 mm/m for all angular parameters and squareness. No scale error was included with this test. Each axis of the machine is 1000 mm.

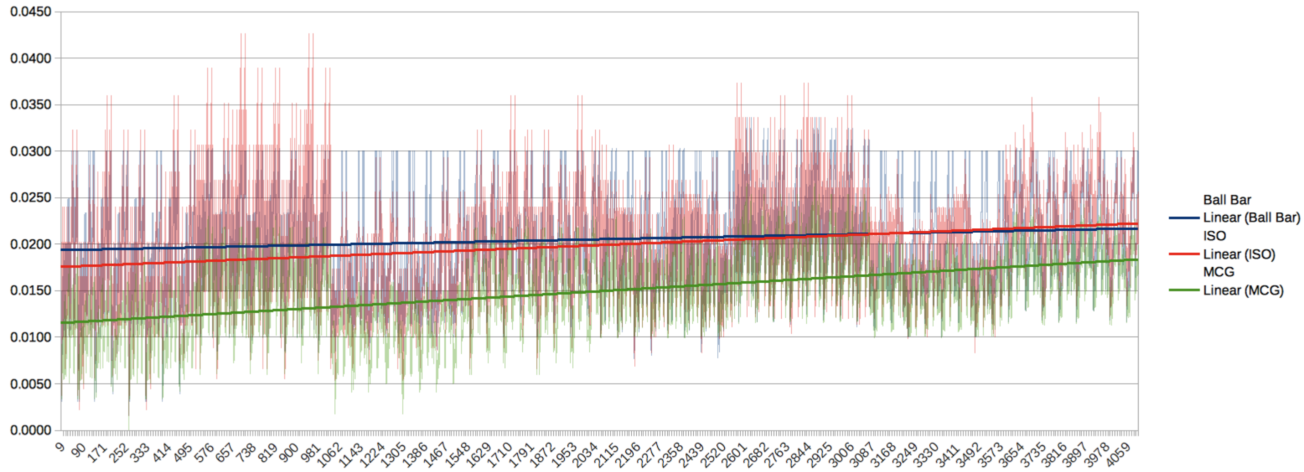

Illustration 13: Graph of ball bar, ISO 10360, and MCG measurement results over all test patterns using an error of 0.010 mm/m.

	ASME B89.4.1:1997	ISO/IEC 10360-2:2009	MCG
Minimum Error	0.0015	0.0015	0.0000
Maximum Error	0.0337	0.0427	0.0266
Average Error	0.0221	0.0221	0.0175
Average Error %	100.00%	99.82%	70.03%
Maximum Error %	78.87%	100.00%	62.31%

The requirements for the ball bar positions of a machine with a cube volume is not the same as a rectangular volume. These results were calculated using the identical measurement pattern described for the rectangular axis tests.

Summary

The following is a list of observations, comments, and opinions about the test results:

- In nearly all cases the magnitude of the ISO/IEC 10360-2 test was significantly larger than that of the ASME B89.4.1 ball bar test for the same amount of machine error.
- Comparison showing percentage results are with respect to the largest error. The largest error is shown as 100% in the summary tables.
- The dimensions of the machine volume have a significant impact on the ASME B89.4.1 ball bar results. The more rectangular the measurement volume (where the ratio of the shortest to longest axis increases) the less sensitive the ball bar results will be to errors related to the longest axis. The best ball bar comparison results appear to be when the machine volume is a cube.
- Both the ASME B89.4.1 and ISO/IEC 10360-2 test results did not show any insensitively to machine errors. The MCG was not able to detect roll errors in the Z axis which is a known issue with this gauge.
- The ISO/IEC 10360-2 performance test requires less measurements as compared to the ASME B89.4.1 ball bar test. Although more complicated to measure there are far less positions to actually measure.
- There is no significant difference in the relationship between the different methods as the magnitude of the machine error increased. The relationship between the different test results did not change with changes in the machine error.
- Due to the symmetrical nature of the ISO/IEC 10360-2 test it is possible that combinations of machine errors can completely negate each other in the measurement results. During a review of the data it was observed that a combination of identical X and Z axis roll, regardless of magnitude, may not appear in the measurement of the E150 positions. The reverse is that the measurement error may double under the right conditions (which is fine as this indicates there is a machine problem).
- These test results do not include influences from probe errors or other common zero-length errors that are typical with an ISO/IEC 10360-2 performance test. The ASME B89.4.1 ball bar test is less sensitive to probe errors so the reported values represent the best case scenario.
- The ASME B89.4.1 ball bar test is not sensitive to scale errors that are common to all axis. Scale errors were not included in the test data as this would unfairly favor the ISO/IEC 10360-2 test. The same applies to the Renishaw Machine Checking Gauge test results.
- The Renishaw Machine Checking Gauge is a reasonably reliable method to quickly evaluate the performance of a coordinate measuring machine. The results are the least sensitive to

machine errors but this inefficiency is offset by the ease of use and speed.

- The measurement of the artifacts following ISO/IEC 10360-2 as compared to ASME B89.4.1 is closer to the actual use of the equipment by the user. Conversion of ASME B89.4.1 data into an estimate of potential measurement error is difficult since it is a fixed length result (the length of the ball bar).

Revision History

Date	*Version*	*Changes*
July 27, 2016	1.0	Initial Release
July 28, 2016	1.1	Revision of total measurement count.
Mar 11, 2018	1.2	Clarification regarding the testing and evaluation of the data. Added an additional comparison test in a cube volume.