Comparison ISO 10360-2 to ASME B89.4.1

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Introduction

This document describes the testing method and results from a comparison of the two major performance testing standards for coordinate measuring machines; ISO/IEC 10360-2:2009 and ASME B89.4.1:1997. The ASME B89.4.10360-2:2008 is identical to ISO/IEC 10360-2:2009 therefore the results apply to both standards.

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 the ball bar testing part of the standard is essentially a length repeatability throughout the measurement volume. The 10360 standard is a 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 different artifacts along a specified measurement line in 9 positions. Each measurement length along any measurement line is done three times for a total of 105 unique measurement results. The largest error from the 105 measurement lengths is the reported measurement value for that particular measurement line.

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:

$$E_l\,MPE = 0.003 + 0.004\,L$$

The specifications is a +/- tolerance. Using the example tolerance with a measurement length of one meter then the tolerance would be +/- 0.007 mm.

ASME B89.4.1 Performance Test

The ball bar is the primary equipment used to test the volume of the machine when following the ASME B89.4.1 standard. This length of the ball bar is uncalibrated so the test is to verify the measurement of length is repeatable throughout the volume of the 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 used when running the ASME B89.4.1 performance test cannot be longer than the shortest axis of the CMM. To address this limitation different patterns of ball bar tests are used for different configurations of CMM axis dimensions.

Testing Criteria

When comparing the two performance standard the following items were 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 errors 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 also be sensitive to all measurement errors in a CMM. If the performance test cannot detect specific types of machine errors then these errors may actually exist in the machine even though the performance test does not reveal any problems. In nearly all cases limitations of the performance test can be supplemented by additional tests but if this is not part of the standard then it may not be done at all.

In addition to the listed criteria it should also be noted that one desirable criteria is speed and simplicity. The measurement of the ISO/IEC 10360-2:2009 pattern consists of 9 measurement positions as opposed to 24, 34, or 39 positions for 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 Method

The test is done by generating a measurement pattern that meets the requirements of the ASME B89.4.1:1997 and ISO/IEC 10360-2 standards on a simulated coordinate measuring machine. The measurement result is calculated for each full performance test using a CMM model that has 0.002, 0.005, and 0.010 mm/m for the test parameters used for the evaluation. The testing is repeated with every possible combination of input machine errors producing a comparison table of results.

Scale errors were not included in the test CMM model. This would put an unfair advantage on the ISO/IEC 10360-2 performance test.

Comparison Data

The following is an example of the comparison output generated by the measurement simulation. The file has four possible groups of measurement listed side by side on a single line of text (only the ball bar 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.

```
                                         |                 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 number of lines in the data file depends on the number of simulated error measurement tests used for the automated comparison. For all available machine errors the output file will have 65535 measurement result entries. For the purpose of this comparison the scale errors and deflection entries were not used resulting in 4095 unique combinations of measurements.

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 CMM model volume used for testing was chosen to be 1000 x 2000 x 1000 mm.

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 measured using a horizontal probe offset of 150 mm. 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 are from each measurement line where the origin of each individual length is the start of the measurement.

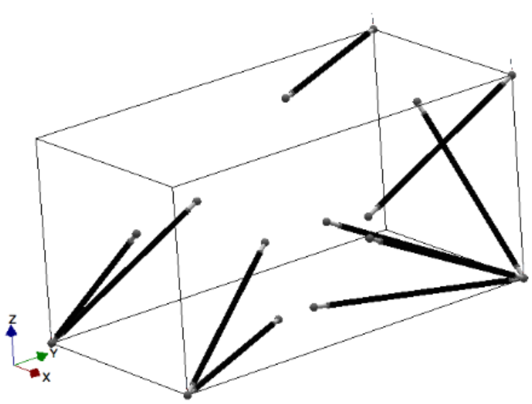

Illustration 1: ball bar positions 1 - 10

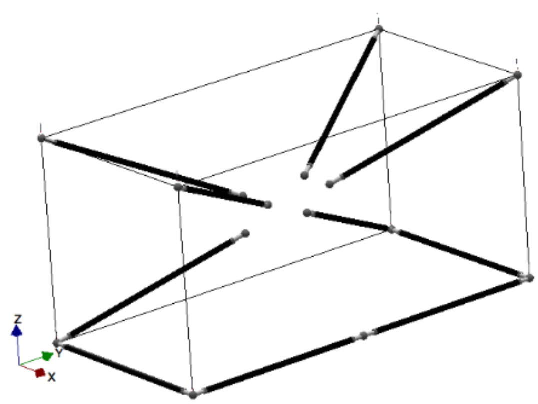

Illustration 2: ball bar positions 11 - 20

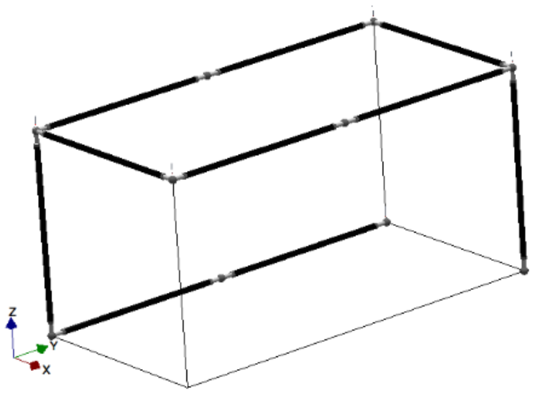

Illustration 3: ball bar positions 21 – 30. ball bar positions 1 – 30 use a basic probe offset.

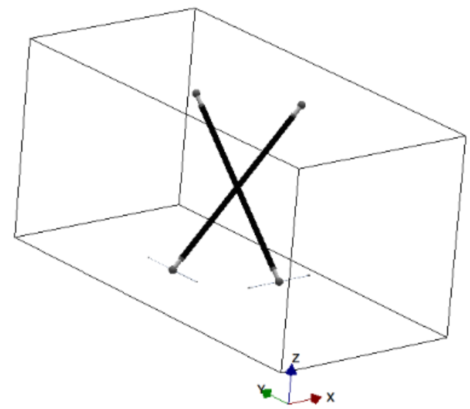

Illustration 4: ball bar positions 31 – 34. Each position is measured twice using an offset probe.

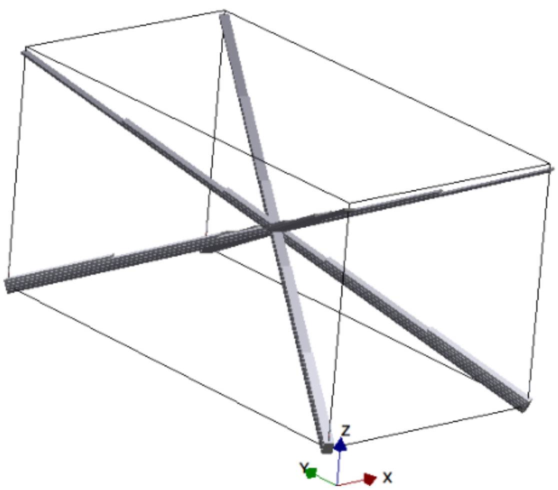

Illustration 5: E0 measurement positions 1 - 4

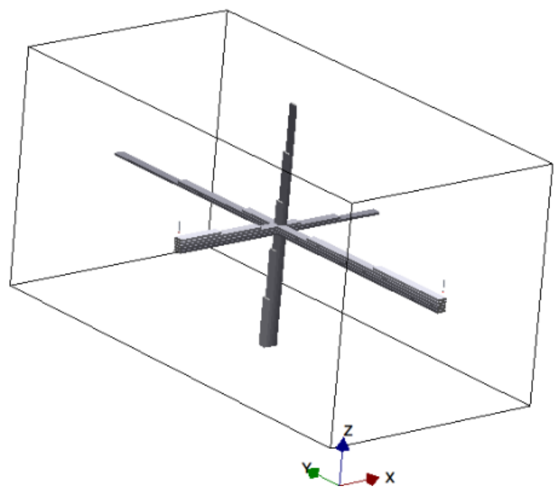

Illustration 6: E0 measurement positions 5 - 7

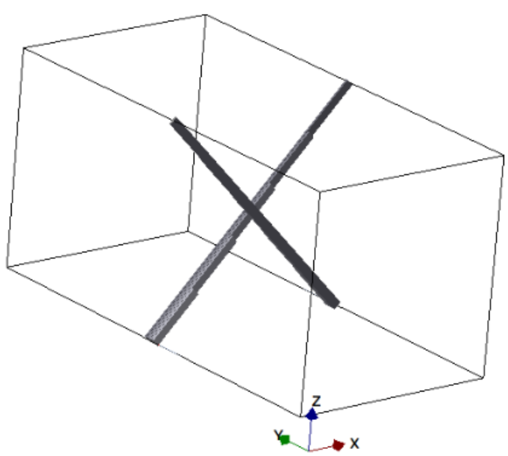

Illustration 7: E150 measurement positions D1 – D2 measured with offset probe.

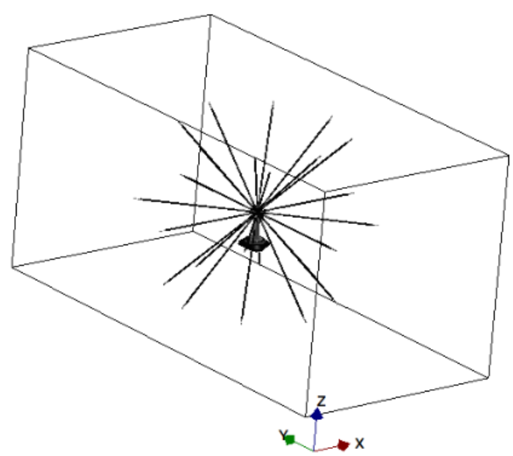

Illustration 8: Renishaw MCG standard 24 position pattern from -45 to 45 degree elevation.

The Renishaw Machine Checking Gauge is not an artifact recommended by either the ASME B89.4.1 or 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 of the two CMM performance standards 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 tests no modification was required as the ball bar nominal length is 1 meter. The measurements of the ISO/IEC 10360-2 tests was 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.

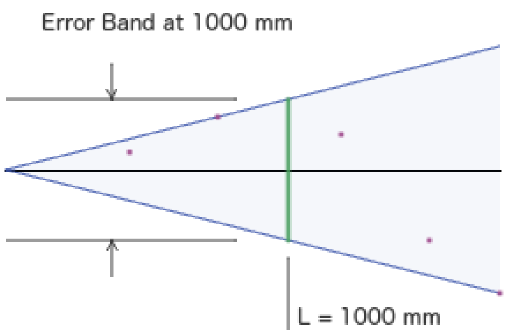

Illustration 9: Calculation of normalized measurement error bandwidth.

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 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.

Machine Error Minimal

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.

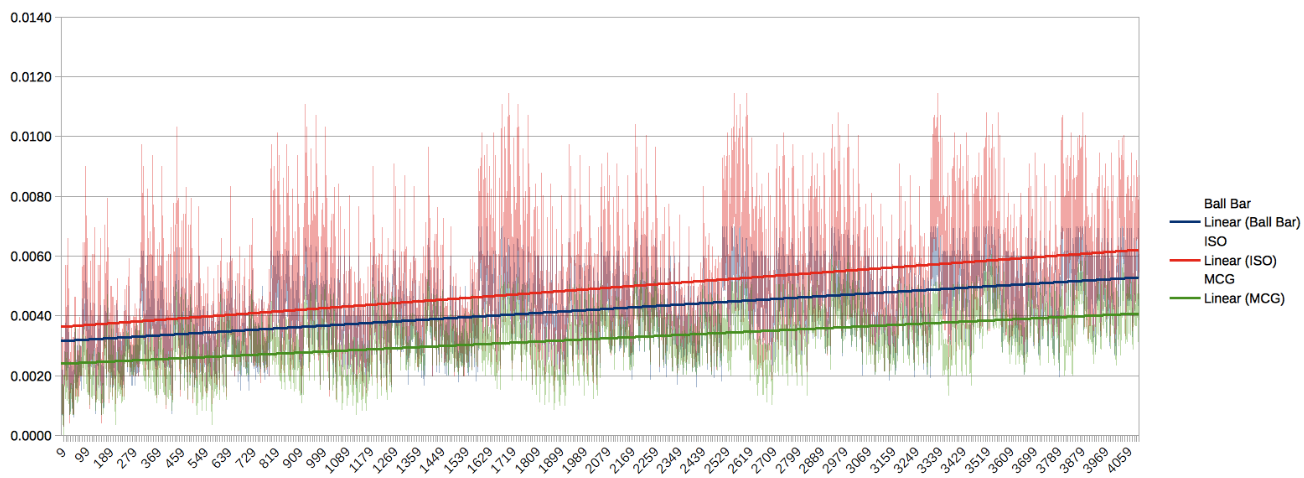

Illustration 10: Graph of ball bar, ISO 10360, and MCG measurement results over all test patterns using an error of 0.002 mm/m.

	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

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.

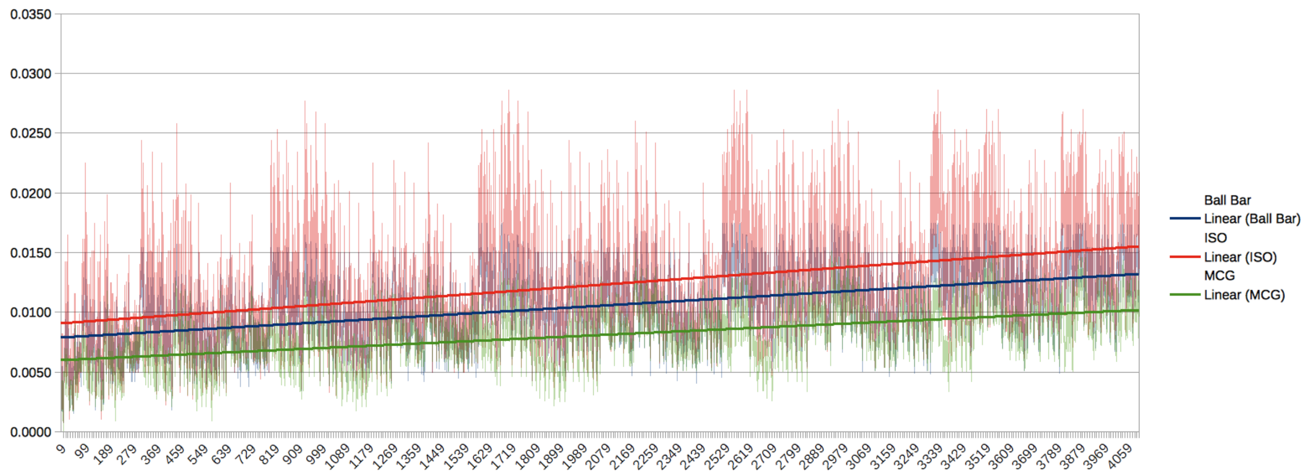

Illustration 11: Graph of ball bar, ISO 10360, and MCG measurement results over all test patterns using an error of 0.005 mm/m.

	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

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.

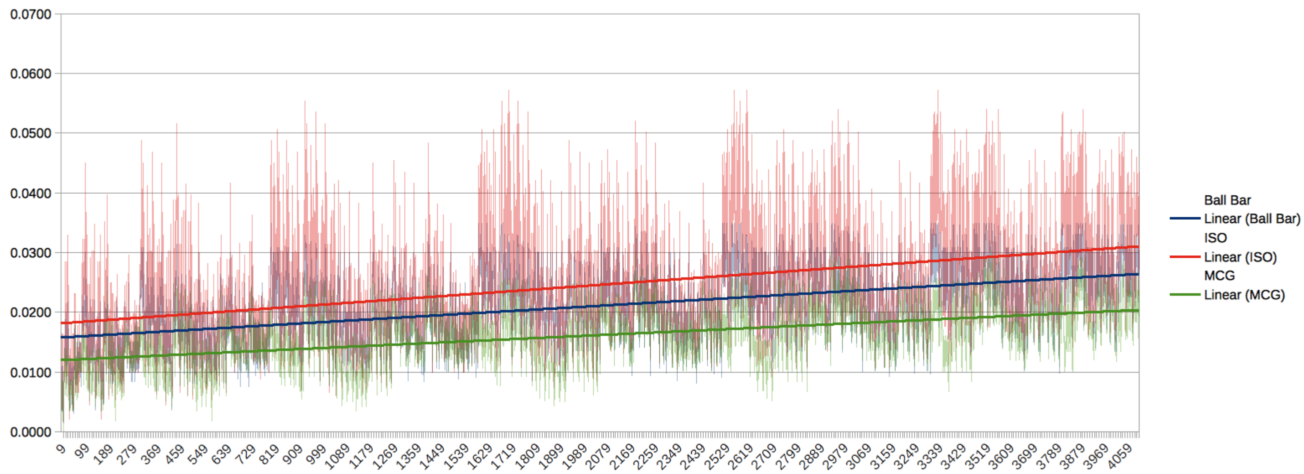

Illustration 12: Graph of ball bar, ISO 10360, and MCG measurement results over all test patterns using an error of 0.010 mm/m.

	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%

Summary

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 this reason all results are shown as a percentage of the 10360-2 results in all the summary tables. In the best possible light the ball bar test showed errors approximately 85% of what the 10360 test reported.

Both the ASME B89.4.1 and ISO/IEC 10360-2 test results did not show any insensitively to machine errors. The minimum errors between the ball bar and 10360 results were nearly identical for each test pattern. The minimum values would indicate if a particular machine error didn't affect any of the measurement results.

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 each position 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. For this reason 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 only observable problem is that this gauge cannot detect Z axis roll errors at all.

One observation about the ASME B89.4.1 ball bar test when performed in the field is that very few actually adhere to the requirements of the standard. Tests that use a custom or subset of ball bar measurements are likely less sensitive to what is shown by these tests. This problem has not been observed with the 10360-2 family of tests.

Revision History

Date	*Version*	*Changes*
July 27, 2016	1.0	Initial Release