SCI Calibration Reports

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Purpose

This document describes the calibration reports generated by Select Calibration Incorporated when testing the performance of Coordinate Measuring Machines. Procedures and recommendations for performance testing and reporting of measurement data is from either the ASME B89.4.10360-2:2008 or ISO/IEC 10360-2:2009 standard.

The ASME B89.4.10360-2 and ISO/IEC 10360-2 standards are virtually identical and subsequently described as simply 10360-2. Differences that do exist will be indicated if the difference is applicable to the calibration report generated by SCI.

Report Sections

The calibration report contains the following sections:

- Information page
- Repeatability R0
- E0 Length Measurements
- E150 Length Measurements
- Summary (optional).
- Revision History (optional).

The calibration report is a minimum of five pages in length. The number of pages is based on the number of measurement tests performed and has no practical upper limit. The summary page is optional and is used to consolidate all measurement results in a single location. The revision history page is optional and used when a change is made to a previously released report.

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Information Section

The first page of the report contains information about the equipment and conditions present during the calibration and is signed by the person of authority when the report is approved. The information page contains a description of the report limits, traceability conditions, description of the uncertainty confidence level, decision rules for compliance statements, and other details related to the remainder of the calibration report.

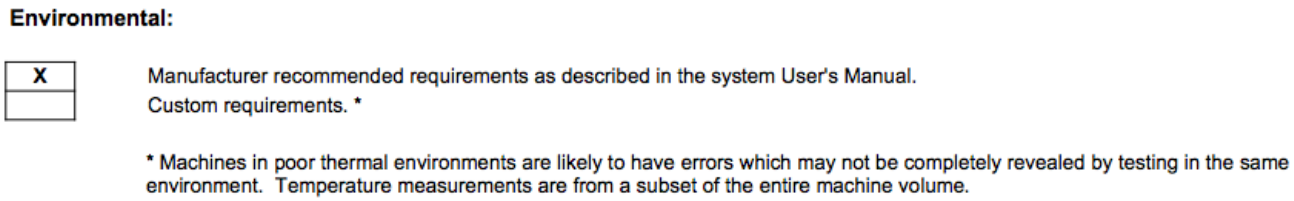
Conditions

The conditions section contains two subsections:

- *Environmental*
- *Adjustment and Reporting*.

Environmental

The environmental condition section indicates if the range of the recorded temperatures while running the performance tests on the Coordinate Measuring Machine stayed within the machine's specification. For a typical CMM the temperature specification is 20°C +/- 2°C with additional sub requirements such as a rate of change over time.



Environmental:

X	Manufacturer recommended requirements as described in the system User's Manual.
	Custom requirements. *

* Machines in poor thermal environments are likely to have errors which may not be completely revealed by testing in the same environment. Temperature measurements are from a subset of the entire machine volume.

Figure 1: Section showing the environmental conditions that existed when testing the CMM.

The environmental condition is reported based on a subset of temperature measurements from the machine scales and artifacts used for the performance test. The environmental condition is not based on the entire machine measurement volume as defined by the standard.

When the environment exceeds the manufacturers specification for temperature the machine tolerance is increased (derated) using methods defined in ASME B89.4.10360-2:2008.

The environment section does not include other factors such as vibration.

Adjustments and Reporting

These indicators show if there were changes to the machine during the calibration. A change can be from a parameter update to the software compensation error map or mechanical adjustments of the CMM that impact the machines measuring performance or a combination of the two.

Due to the nature of CMM calibration and the data collection process this option will always indicate that changes were made to improve performance even if all changes are at the level

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considered to be measurement noise (limits of the equipment). Calibrations performed by SCI involve measuring and updating all compensation parameters in a semi-automated method that does not involve handling or interpreting of measurement data by the operator.

Comparison of the original and updated compensation error map data can be used to attach a value to the amount of change in the machine if this information is required.

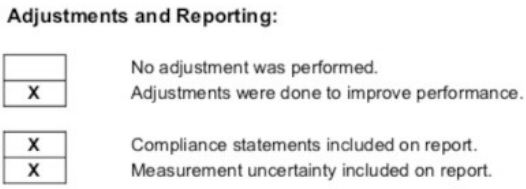

Figure 2: Section showing the Adjustment and Reporting options.

Reporting of the compliance statements and measurement uncertainty is optional and can be disabled if requested. These indicators will show if the compliance statements or measurement uncertainty was included on the report.

Reference Standards and Unit Under Test

The *Reference Standards and Unit Under Test* section describe the artifacts used for testing and some details of the CMM that influence the test results.

Reference Standards

This section describes the equipment used for the performance test of the CMM. This list does not extend to the equipment used to collect compensation error map data unless this equipment was also used as part of the performance test of the CMM.

All equipment has a description, serial number, calibration date, and calibration due date. Equipment that has a physical length will show the nominal length under the length column. The expansion coefficient for artifacts will only be shown for suitable equipment.

Reference Standards and Unit Under Test

Description	Standard ID	CTE	Length	Cal. Date	Due Date
Step Gauge	**SG-1520007**	**10.8**	**1010.0**	**Apr 9 2020**	**Apr 15 2021**
Thermometer	**T-75014120711-141732**			**Sep 30 2019**	**Sep 30 2020**
Laser	**L-4975**			**Apr 22 2019**	**Apr 22 2021**
Gauge Block	**GB-131417**	**10.8**	**12.7**	**Apr 13 2020**	**Apr 15 2022**

Figure 3: Section showing the reference standards used for testing the CMM.

Unit Under Test

The machine scale resolution, configuration of probe, and axis expansion coefficient can be a significant contributor to measurement error and measurement uncertainty and is therefore listed in this section of the report. The calculated measurement uncertainty is partially based on the

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coefficient of thermal expansion of the machine axis, the resolution of the scales, the probing uncertainty, and the environmental conditions that existed during the testing of the CMM.

The expansion coefficient (CTE) of the machine scales is the functional expansion coefficient of all axis during testing. Machines that have active scale temperature compensation that cannot be switched off by the user will have an effective CTE of zero.

The type of probe and stylus used for performance testing is an influence on the final reported measurement results and is therefore listed in this section of the report.

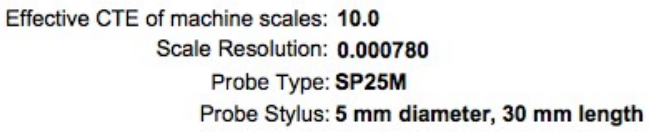

Figure 4: Section showing details of the CMM that influence the measurement results and reported uncertainty.

The type of probe used when running the performance tests is always the one with the lowest measurement uncertainty if multiple options exist unless specifically requested by the customer.

The specifications for CMM's often change with different configurations of probes and probe stylus. Machine specifications will describe the probe and stylus configuration that is expected to be used for testing.

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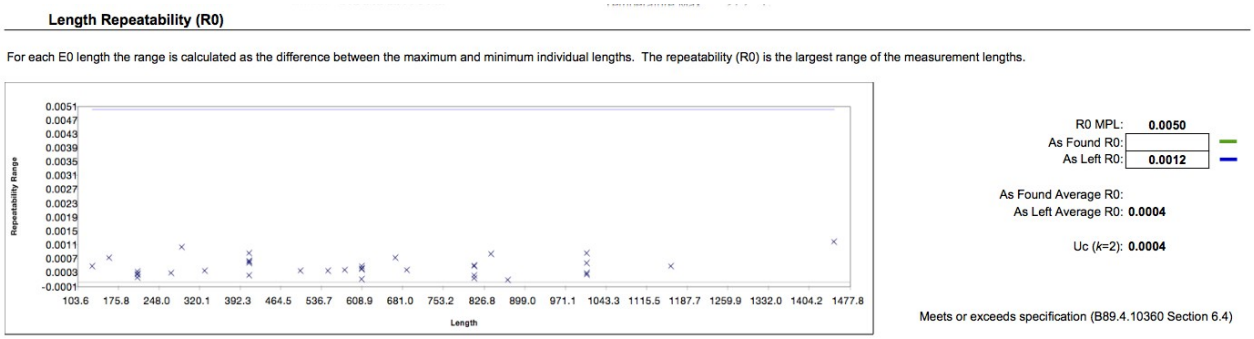
Repeatability

The repeatability page shows the R0 length repeatability results.

Length Repeatability R0

This measurement of repeatability is evaluated from the E0 measurements and describes the largest length repeatability found from all the sets of E0 length measurements.



Description	Nominal	Range	Description	Nominal	Range	Description	Nominal	Range	Description	Nominal	Range	Description	Nominal	Range
Position 1	210	0.0002	Position 5	160	0.0007									
As Left	410	0.0002	As Left	330	0.0003									
	610	0.0005		500	0.0003									
	810	0.0001		670	0.0007									
	1010	0.0008		840	0.0008									
Position 2	210	0.0001	Position 6	290	0.0010									
As Left	410	0.0006	As Left	580	0.0003									
	610	0.0004		870	0.0001									
	810	0.0005		1160	0.0005									
	1010	0.0005		1450	0.0012									
Position 3	210	0.0003	Position 7	130	0.0005									
As Left	410	0.0008	As Left	270	0.0003									
	610	0.0001		410	0.0006									
	810	0.0005		550	0.0003									
	1010	0.0002		690	0.0004									
Position 4	210	0.0002												
As Left	410	0.0006												
	610	0.0004												
	810	0.0002												
	1010	0.0003												

Figure 5: Evaluation of length repeatability from the E0 measurement positions.

Each E0 measurement line consists of five lengths measured three times. The range of the three measured lengths is calculated for each of the five measurement lengths. The length range is shown on the R0 graph with the largest range in length reported for R0. The length range is also displayed as a numerical value below the graph for each E0 nominal length.

The length repeatability R0 is separated into *As Found* and *As Left* results. The numerical display of data includes identification of the *As Found* and *As Left* data.

R0 MPL

Tolerance limit for the repeatability test (*maximum permissible limit*).

R0

Largest repeatability range from all the E0 measurement lengths.

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This maximum R0 is from the largest single deviation of the data. There is no statistical filtering of the data such as using an average or estimate of range from the standard deviation. It has been observed that using this value for comparison purposes, particularly when comparing the As Found to the As Left is not a good idea where the Average R0 should be used for this purpose instead. It is not expected to see a significant difference between As Found and As Left data in general but many factors exist that could make the two appear different.

Average R0

Average repeatability of all the E0 measurement lengths.

This average R0 is reported to provide an indication of the average repeatability of length. This value is not required by the 10360-2 standard but it does provide an indicator on how comparable the results are between the As Found and As Left results.

Uc

Shows the calculated measurement uncertainty for the R0 measurement expanded to a coverage level of 95%.

Description

Name of the E0 measurement line and indicator for *As Found* and *As Left* data.

Nominal

Nominal length of the measurement. The nominal length is rounded to a non-precision value but otherwise identical to the nominal length for each measurement length of each measurement line.

Range

Range of the measurement lengths. The largest range of lengths is the value reported for R0.

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Length Measurement

The length measurement pages show detailed results from the individual E0 and E150 measurement tests. The minimum number of measurement lines is seven E0 and two E150.

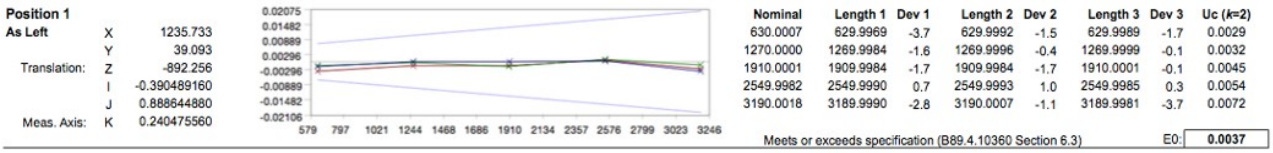

Illustration 1: Report section for a single measurement line consisting of fifteen measurement lengths.

The E0 measurement tests are performed with a zero (or minimal) probe offset perpendicular to the third axis of the CMM. The E150 measurement tests are performed with a probe offset of approximately 150 mm perpendicular to the third axis of the CMM. The E0 and E150 tests are virtually identically other than the probe offset. Collectively these two categories of measurements are referenced as E_L.

Test Method

Each measurement line through the volume of the CMM is broken down into five proportional lengths (rounded to the nearest 10 mm). The measurement line for E0 positions 1 to 4 is along the XYZ diagonals of the machine while E0 positions 5 to 7 are parallel to the X,Y, and Z axis of the machine. The E150 positions are measurements in the YZ or ZX planes of the CMM using an offset probe with a nominal length of approximately 150 mm.

The reported measurement value is the distance between two bidirectional and unique points measured for each length. When using a laser as the certified length standard the measurement is supplemented with a short gauge block to re-create the bidirectional measurement component that would only exist when using a physical artifact.

Nominal	Length 1	Dev 1	Length 2	Dev 2	Length 3	Dev 3	Uc (*k*=2)
629.9976	629.9999	2.3	629.9991	1.5	629.9984	0.8	0.0014
1269.9979	1269.9989	1.0	1269.9982	0.3	1269.9984	0.6	0.0025
1909.9966	1909.9986	2.0	1909.9989	2.3	1909.9975	0.9	0.0036
2550.0003	2549.9989	-1.4	2550.0000	-0.3	2550.0006	0.3	0.0048
3190.0037	3189.9999	-3.8	3189.9988	-4.9	3189.9989	-4.8	0.0059

Meets or exceeds specification (ISO 10360-2 Section 6.3) E0: **0.0049**

Figure 6: Extraction of measurement from measurement position.

The nominal lengths, actual lengths, and measurement uncertainty estimates are reported using the base reporting units (typically millimeters). The deviations between the nominal and actual lengths are reported using the deviation reporting units (typically micrometers).

The largest deviation from any of the individual measurement lengths from a single measurement line is the reported E_L value. Figure 6 shows an example of an E_L measurement and how the final result is extracted from the data.

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Translation

The starting position in the machine volume for the measurement line. This position is the zero location of all the five measurement lengths performed along the measurement line.

Meas. Axis

Direction within the machine volume of the measurement line.

Nominal

Nominal length for all measurements.

Length N

Actual measured length from a pair of the six measurement points. There are three sets of length measurements calculated from the six measurement points.

Dev N

Deviation of the measurement length from the nominal length. The deviation is the difference from the nominal and actual length.

Uc

Shows the calculated measurement uncertainty expanded to a coverage level of 95%.

E0 or E150 Value

Value that represents the largest measurement deviation from a single measurement line. This value is the largest absolute deviation from the nominal length.

As Found or As Left Max E0 or E150

Value that represents the largest measurement deviation from all the E0 or E150 positions. When the report contains a combination of *As Found* and *As Left* measurement positions there will be four separate values (*As Found* Max E0, *As Left* Max E0, *As Found* Max E150, and *As Left* Max E150).

E0 or E150 MPE

Value that represents the largest measurement deviation allowed *(maximum permissible error*). This value is expressed as a formula.

Deration

Amount of adjustment of the machine specification as defined by ASME B89.4.10360-2:2008 when the temperature exceeds the manufactures limits.

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Summary

The summary page shows the consolidation of all the measurement results in one location.

Length Repeatability (R0)

For each E0 length the range is calculated as the difference between the maximum and minimum individual lengths. The repeatability (R0) is the largest range of the measurement lengths.

R0 MPL:	0.0050
R0:	0.0012
Uc (*k*=2):	0.0004

Length Measurement Error (E0 and E150)

Five calibrated test lengths are measured three times with a zero (or minimal) tip offset for E0 and a 150 mm (5.9") tip offset for E150 . The length measurement error is the maximum length deviation from the fifteen length measurements.

Max E0:	0.0034
Max E150:	0.0023

E0 MPE: **0.0045+0.0025L/1000*** Deration: Percentage of maximum error relative to out of tolerance E0: **37.1%**

E150 MPE: **0.0045+0.0025L/1000*** Deration: Percentage of maximum error relative to out of tolerance E150: **31.2%**

Position 1

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
209.9932	1.6	1.8	1.8	0.0015
409.9955	2.0	2.0	1.9	0.0017
609.9996	2.0	1.9	2.4	0.0021
810.0010	2.4	2.3	2.3	0.0024
1010.0003	3.4	2.6	3.0	0.0028

Position 2

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
209.9932	-1.1	-1.0	-1.1	0.0015
409.9955	-0.5	-0.7	0.0	0.0017
609.9996	0.6	0.6	1.0	0.0021
810.0010	2.2	2.2	1.7	0.0024
1010.0003	2.3	2.8	2.8	0.0028

Position 3

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
209.9932	-0.6	-0.8	-0.9	0.0015
409.9955	-1.0	-0.7	-0.2	0.0017
609.9996	0.9	0.9	1.0	0.0021
810.0010	2.1	1.6	1.8	0.0024
1010.0003	2.7	2.8	2.6	0.0028

Position 4

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
209.9932	-0.1	-0.1	0.1	0.0015
409.9955	0.6	0.0	0.2	0.0017
609.9996	2.2	1.9	1.8	0.0021
810.0010	1.4	1.5	1.6	0.0024
1010.0003	3.2	3.3	3.4	0.0028

Position 5

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
159.9996	1.5	1.6	0.9	0.0011
330.0002	0.6	0.7	0.4	0.0012
500.0001	0.3	0.6	0.6	0.0014
669.9998	-0.1	0.4	0.6	0.0016
839.9979	3.0	3.1	2.3	0.0018

Position 6

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
290.0007	0.8	-0.2	-0.1	0.0012
580.0008	-0.1	0.0	-0.3	0.0014
870.0005	0.0	0.1	0.1	0.0018
1160.0008	-0.5	-0.9	-1.0	0.0022
1450.0014	0.0	0.1	-1.1	0.0026

Position 7

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
130.0001	0.4	-0.1	0.3	0.0011
270.0009	0.0	-0.2	0.1	0.0012
410.0001	1.7	1.5	1.1	0.0013
550.0009	0.1	-0.2	0.2	0.0015
690.0008	-0.1	-0.4	-0.2	0.0017

Position D1

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
209.9932	-0.9	-2.0	-1.6	0.0015
409.9955	-1.9	-2.3	-1.9	0.0017
609.9996	-0.7	-0.5	-1.2	0.0021
810.0010	0.1	-0.6	-0.2	0.0024
1010.0003	0.8	0.7	0.7	0.0028

Position D2

Nominal	Dev 1	Dev 2	Dev 3	Uc (*k*=2)
209.9932	-0.2	-0.2	-0.5	0.0015
409.9955	0.4	0.9	0.4	0.0017
609.9996	-0.4	0.2	-0.4	0.0021
810.0010	1.7	1.9	1.2	0.0024
1010.0003	1.9	2.1	1.8	0.0028

Figure 7: Data section of summary page.

The summary page has a limit of fifteen E0 and E150 measurements. When reports are generated that contain more than fifteen measurement lines then this page is not included.

Percentage of Maximum Error To Out of Tolerance

This field represents the worst result of the measured data relative to the strict rejection limit and described as a percentage. A value greater than 100% means that the compliance statement for one or more measurement positions shows that the result does not meet specification.

The worst result is the largest error relative to the specification limit and is not necessarily the largest deviation from nominal. The specification limit is not a fixed value and increases based on the measurement length. For example, a deviation of 0.003 mm at a length of 100 mm will likely be worse than a deviation of 0.004 mm at length 1000 mm since the specification is greater at 1000 mm as compared to 100 mm.

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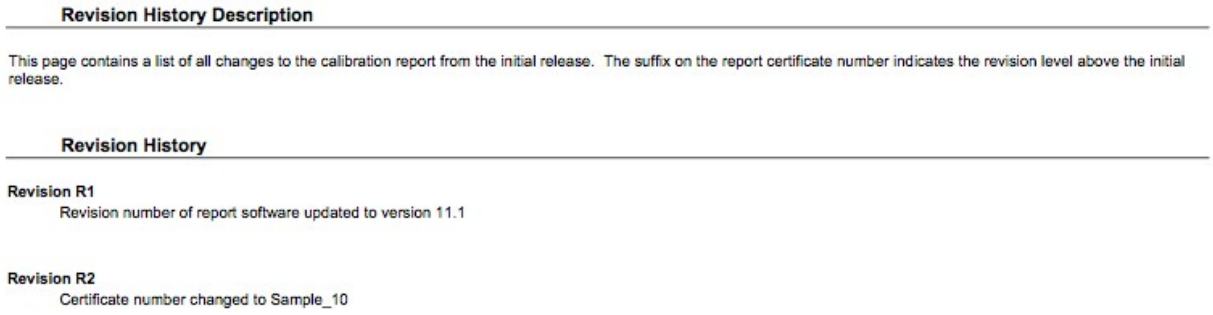
Revision History

The revision history page contains a list of all changes to the calibration report from the initial release. Changes could be made for a variety of reasons and those reasons are listed in chronological order on this page of the report.



Revision History Description

This page contains a list of all changes to the calibration report from the initial release. The suffix on the report certificate number indicates the revision level above the initial release.

Revision History

Revision R1
Revision number of report software updated to version 11.1

Revision R2
Certificate number changed to Sample_10

Figure 8: Revision history example data.

This page of the report only exists when a revision has been made.

Legacy Reporting

Calibration reports prior to Apr 2020 included the point repeatability test, Rpt, but was removed from the current calibration reports and testing procedures. The point repeatability test is identical to the sphere repeatability tests from the legacy versions of the ASME B89.4.1:1997 standard. The test procedure and data interpretation from the legacy point repeatability test is described in the following section.

Point Repeatability Rpt

The point repeatability test is the measurement of a centrally located precision sphere repeated ten times as rapidly as practical. For each axis the range of the sphere center coordinate is calculated as the difference between the maximum and minimum value. The point coordinate repeatability, Rpt, is the largest range of coordinate values measured.

The Rpt test is not defined in ISO/IEC 10360-2:2009 but is included as a functional test for this standard.

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Point Repeatability (Rpt)

Repeated measurements of a centrally located precision sphere repeated ten times as rapidly as practical. For each axis the range of the sphere center coordinate is calculated as the difference between the maximum and minimum value. The point coordinate repeatability (Rpt) is the largest range of coordinate values measured.

X Axis

Measurement:	1	2	3	4	5	6	7	8	9	10
Result:	0.0	0.5	-0.6	-0.3	-1.6	0.0	-0.4	0.2	0.3	0.1

Min	Max	Range
-0.0016	**0.0005**	**0.0020**

Rpt MPL: **0.0030**
Rpt: **0.0029**

Y Axis

Measurement:	1	2	3	4	5	6	7	8	9	10
Result:	0.0	0.5	0.5	0.9	1.1	1.9	1.9	1.4	1.3	0.6

Min	Max	Range
0.0000	**0.0019**	**0.0019**

Uc (*k*=2): **0.0007**

Z Axis

Measurement:	1	2	3	4	5	6	7	8	9	10
Result:	0.0	-0.6	-0.6	-2.5	-1.6	0.5	-0.9	-0.3	-0.4	-0.2

Min	Max	Range
-0.0025	**0.0005**	**0.0029**

Compliance is unknown (B89.4.10360 Section 5.4.1)

Illustration 2: Point repeatability test, Rpt, measured on a sphere

The individual sphere measurement positions are reported as a deviation from the initial sphere position and shown using the deviation reporting units (typically micrometers). The summary showing the minimum, maximum, and range is displayed in the base reporting units (typically millimeters). The largest range from the X, Y, or Z axis is the value reported for Rpt.

X Axis

Measurement:	1	2	3	4	5	6	7	8	9	10
Result:	0.0	0.5	-0.6	-0.3	-1.6	0.0	-0.4	0.2	0.3	0.1

Min	Max	Range
-0.0016	**0.0005**	**0.0020**

Illustration 3: Example showing extraction of values to represent the repeatability range for the data along the X axis. The largest range of the three axis is the reported Rpt value.

The Rpt measurement is not separated into As Found and As Left results. This kind of repeatability is considered to be a characteristic of the machine and is not influenced by typical changes from calibration.

Rpt MPL

Tolerance limit for the repeatability test Rpt *(maximum permissible limit*).

Rpt Value

Largest repeatability range from the three machine axis.

Uc

Shows the calculated measurement uncertainty expanded to a coverage level of 95%.

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Reporting Units

The calibration report can be generated in metric or imperial with deviations shown in units that are a fraction of the base unit. A typical report is created in metric (mm) with deviation units of 0.001 mm (micrometers) but reports can also be generated using the imperial system (Inch) with deviation units of 0.001” or 0.0001”.

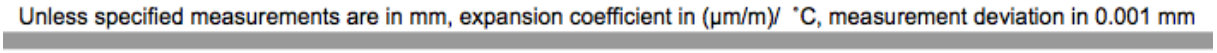

Figure 9: Description of reporting units shown at bottom of each page.

Expansion coefficients units for metric reports are um/m/°C where imperial expansion coefficients units are uIn/In/°F.

Calibration reports using the imperial units are uncommon.

Interpretation of Measurement To Specification

Measurement uncertainty is considered when comparing a measurand to a specification. In the example shown in illustration 4, four sets of measured values are displayed relative to a tolerance. Each measurand has the expanded uncertainty drawn around the value to show the relative range for each item.

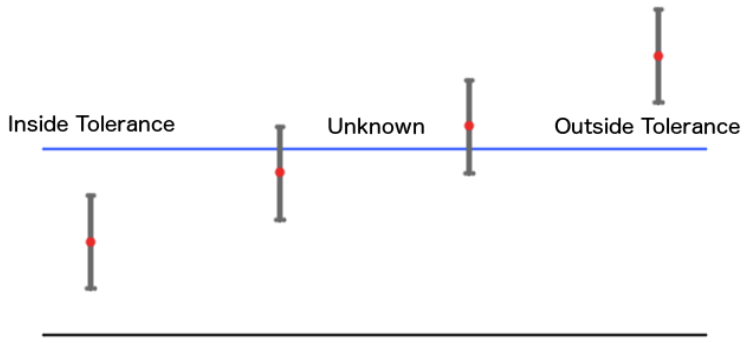

Illustration 4: Examples of measurements shown with the expanded uncertainty for each.

Based on the results shown in illustration 4 only the first and last measurement will be stated as inside or outside of tolerance. The two middle results cannot be stated with the necessary level of confidence and will be described as *compliance unknown* on the measurement report.

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Revision History

Revision	*Date*	*Reason*
1	Oct 11, 2016	Initial Release
2	Nov 27, 2017	Updated information in document.
3	Feb 24, 2018	Updated with changes in the format of the calibration report.
4	Nov 7, 2018	Revision of calibration report format and content.
5	Apr 16, 2020	Revision of calibration report format and content.
6	Nov 3, 2020	Document review.
7	Mar 2, 2021	Added information related to Revision History page.
8	Feb 22, 2022	Changes from document review.
9	Mar 12, 2023	Change in the wording from *No adjustment was necessary to meet specifications* to *Adjustments were not performed.*
10	Apr 19, 2026	Document review following revisions to calibration reports.

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