CMM Specifications Users Guide

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Introduction

The *CMM Specifications* utility allows the user to access the limits for various brands and models of CMM's when running performance tests of the machine as defined by standards such as ISO/IEC 10360-2:2009. The information is stored in a SQLite database and can be converted to a CSV file for importing or exporting as needed.

The sample database has publicly available specifications for various CMM's collected over the years. Although there has been a lot of effort to keep the information correct it is highly probable that some of the data is not valid for various reasons. Additions or revisions are welcome and the sample database on the website will be updated to contain the latest information.

Overview

The *CMM Specifications* utility consists of a main window with selections for the CMM *Make*, *Model*, and *Option* resulting in the display of known and estimated specifications. The CMM *Make* and *Model* are loosely defined by the manufacturer where the *Option* can be anything relevant such as the probe configuration or environment. Illustration 1 shows an example of specification information from a selected *Make*, *Model* and *Option*.

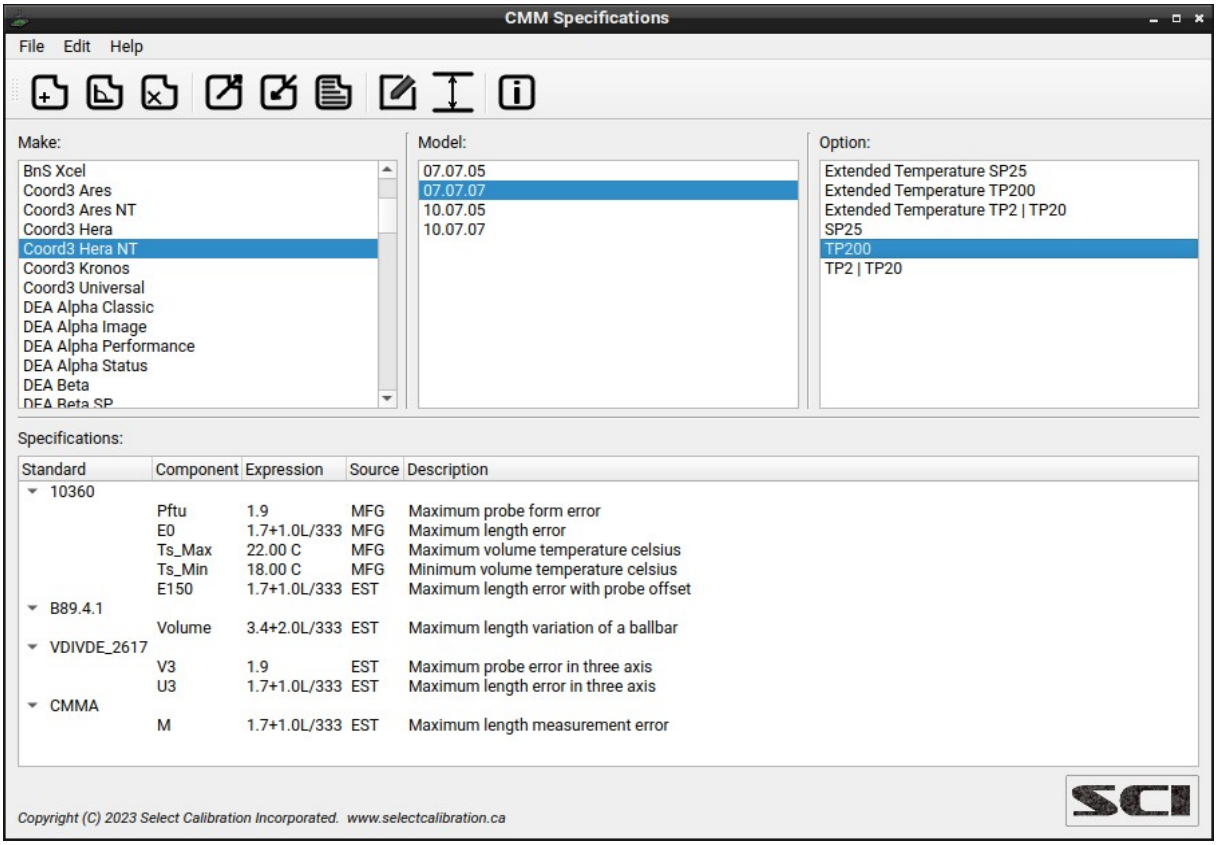


Illustration 1: CMM Specifications utility main window.

The *CMM Specifications* utility uses a SQL database to store information. Previous versions of similar utilities used an XML file for the data which works fine provided the number of entries is

reasonable but this approach becomes exponentially slower as the number of entries increase.

There are four standards supported by the *CMM Specifications* utility: ISO/IEC 10360 / ASME B89.4.10360, VDIVDI 2617, CMMA, and ASME B89.4.1. The ISO/IEC 10360 and ASME B89.4.10360 standards are parallel standards and considered identical and simply referred to a 10360. The CMMA and B89.4.1 standards are obsolete but provided since they are still used for testing the performance of a CMM in some cases. Although all standards are extensive and cover a variety of tests only a subset is used that are considered relevant to the performance testing of a typical CMM from a calibration point of view.

The ability to support other measurement standards or tests can be added if the need arises. One example would be the scanning tests defined in 10360-4 which are not included in this utility. Some tests such as 10360-5 Pftu (originally in 10360-2:2001 and called MPEp) are in a grey area where it may be relevant to the performance of the CMM or could be considered related to the probe configuration only. The goal is to cover aspects of the machine using the minimum (defined) probe configuration so anything outside of this is ignored.

Toolbar:

Icon	*Description*
	Create a new database file. If an existing database file is selected an option to clear the database is provided.
	Open an existing database file.
	Close the database.
	Export data from the database to a CSV file. This can be all the data or selected entries.
	Import data from a CSV or XML file to the current database. The data is merged unless it aligns with an existing *Make*, *Model*, and *Option* in which case the existing data is replaced.
	Create a presentable PDF file containing the specification for the selected *Make*, *Model*, and *Option*.
	Open the specification editor in order to create or update specification entries.
	Display the specifications limits for various standards based on a measured length and actual temperature.
	Information and version of the *CMM Specification* utility.

Specifications

The specifications displayed for any configuration of *Make*, *Model*, and *Option* consist of two types: specifications entered by the user, and estimated specifications. The data entered by the user is from published or known information about the CMM and is identified with the title MFG (short for *manufacturer*) as the data source. Derived specifications is a reasonable approximation and is identified with the title EST (short for *estimated*). Illustration 2 shows an example of manufacturer and estimated specifications for a selected CMM.

Specifications:

Standard	Component	Expression	Source	Description
10360				
	Pftu	1.9	MFG	Maximum probe form error
	E0	1.7+1.0L/333	MFG	Maximum length error
	Ts_Max	22.00 C	MFG	Maximum volume temperature celsius
	Ts_Min	18.00 C	MFG	Minimum volume temperature celsius
	E150	1.7+1.0L/333	EST	Maximum length error with probe offset
B89.4.1				
	Volume	3.4+2.0L/333	EST	Maximum length variation of a ballbar
VDIVDE_2617				
	V3	1.9	EST	Maximum probe error in three axis
	U3	1.7+1.0L/333	EST	Maximum length error in three axis
CMMA				
	M	1.7+1.0L/333	EST	Maximum length measurement error

Illustration 2: List of manufacturer and estimated specifications.

Estimating the specifications is sometimes necessary when performing a modern performance test on a CMM that only lists data from older or obsolete standards. Illustration 3 shows an example of CMM specifications for an older machine. The only information available for this particular CMM was the ASME B89.4.1 sphere repeatability and ball bar volume repeatability limits, the CMMA repeatability limit, older 10360-2 limits, and the temperature limits.

Specifications can be defined by the end-user of the equipment. It is often the case that the end-user will have requirements for the equipment that differ from the manufacturer's limits. When no information is available specifications can be determined by considering the strict-acceptance limits from a modern performance test.

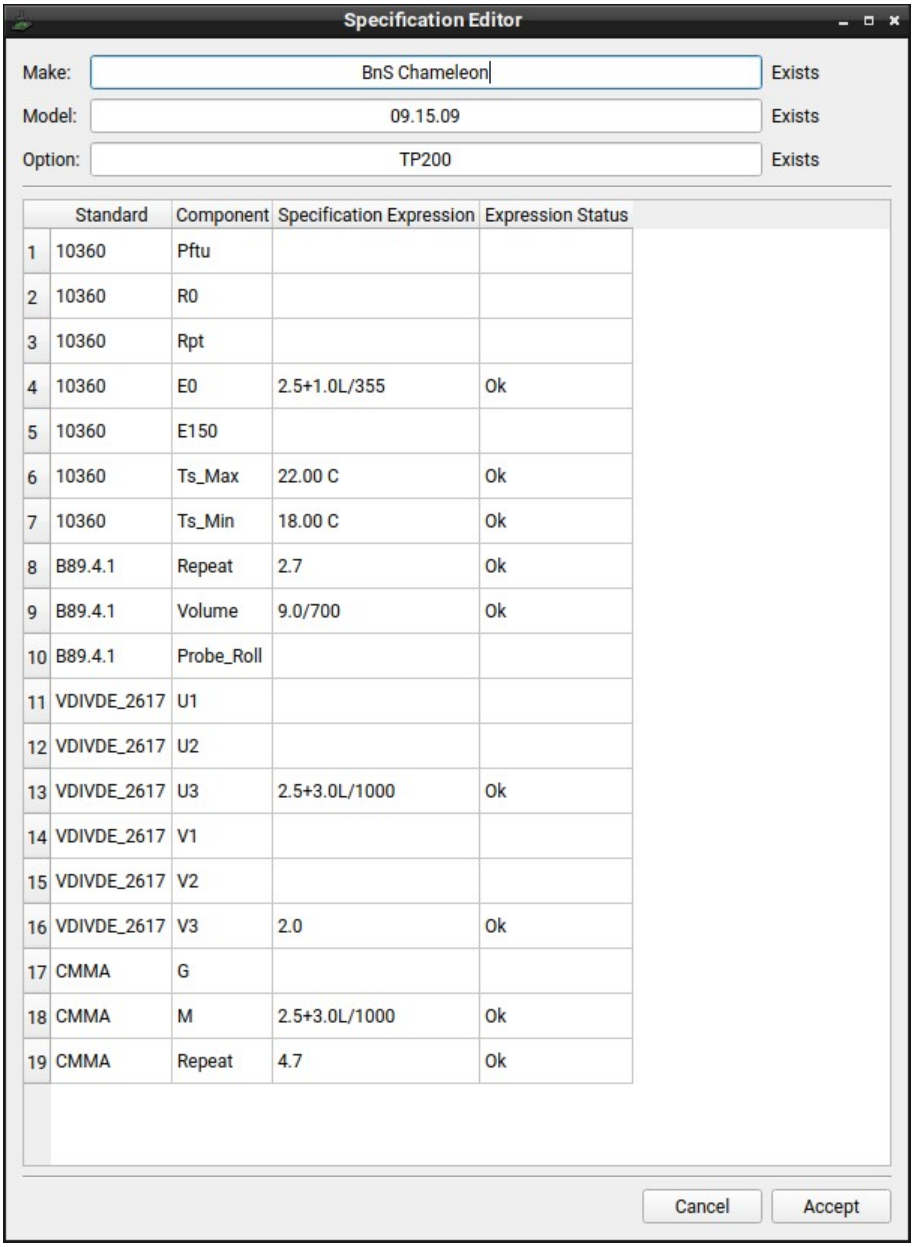
Specifications:

Standard	Component	Expression	Source	Description
10360				
	E0	2.5+1.0L/355	MFG	Maximum length error
	Ts_Max	22.00 C	MFG	Maximum volume temperature celsius
	Ts_Min	18.00 C	MFG	Minimum volume temperature celsius
	E150	2.5+1.0L/355	EST	Maximum length error with probe offset
	Rpt	2.7	EST	Maximum sphere position variation
	R0	5.4	EST	Maximum length variation for E0
	Pftu	2.0	EST	Maximum probe form error
B89.4.1				
	Repeat	2.7	MFG	Maximum sphere position variation
	Volume	9.0/700	MFG	Maximum length variation of a ballbar
VDIVDE_2617				
	U3	2.5+3.0L/1000	MFG	Maximum length error in three axis
	V3	2.0	MFG	Maximum probe error in three axis
CMMA				
	M	2.5+3.0L/1000	MFG	Maximum length measurement error
	Repeat	4.7	MFG	Maximum length variation error

Illustration 3: Specification list for an older machine listing only ASME B89.4.1, partial 10360, and CMMA standards.

Specification Editor

The specification editor allows the creation or updating of specifications for any CMM. Illustration 4 shows an example of the specification editor for a selected CMM.



	Standard	Component	Specification Expression	Expression Status
1	10360	Pftu		
2	10360	R0		
3	10360	Rpt		
4	10360	E0	2.5+1.0L/355	Ok
5	10360	E150		
6	10360	Ts_Max	22.00 C	Ok
7	10360	Ts_Min	18.00 C	Ok
8	B89.4.1	Repeat	2.7	Ok
9	B89.4.1	Volume	9.0/700	Ok
10	B89.4.1	Probe_Roll		
11	VDIVDE_2617	U1		
12	VDIVDE_2617	U2		
13	VDIVDE_2617	U3	2.5+3.0L/1000	Ok
14	VDIVDE_2617	V1		
15	VDIVDE_2617	V2		
16	VDIVDE_2617	V3	2.0	Ok
17	CMMA	G		
18	CMMA	M	2.5+3.0L/1000	Ok
19	CMMA	Repeat	4.7	Ok

Illustration 4: Specification editor.

Options:

Option	*Description*
Make	Name of the make of the CMM.

Option	*Description*
Model	Name of the model of the CMM.
Option	Name of the configuration option for the CMM.
Standard	Identification of the performance standard.
Component	Identification of the test parameter.
Specification Expression	Value or expression representing the limit of the result when performing the specific test.
Expression Status	Indicator of the validity of the entered expression.
Cancel	Close dialog and ignore all changes.
Accept	Accept all changes.

Entry Value or Expression Types

Entries for any specific specification component must meet requirements defined internally for each component. For example, the specification for Pftu from ISO/IEC 10360 is expected to be a single value where the E0 limit from ISO/IEC 10360 is expected to be an expression that includes the measurement length.

Illustration 6 shows examples of entries that are in a valid form but not suitable for the specific specification component item they have been assigned to.

	Standard	Component	**Specification Expression**	Expression Status
1	10360	Pftu		
2	10360	R0	7/1000	Invalid
3	10360	Rpt	2+3L/1000	Invalid
4	10360	E0	3	Invalid
5	10360	E150		
6	10360	Ts_Max	22.00 C	Ok
7	10360	Ts_Min	18.00 C	Ok
8	B89.4.1	Repeat	2.7	Ok
9	B89.4.1	Volume	9.0/700	Ok

Illustration 5: Example of entries not suitable for the selected specification component type.

Length Expression Types

Entries for length expressions can be in one of several acceptable formats. Although intended to be as flexible as possible any variation from an accepted format will be rejected. Some formats are exclusive to specific standards such as the short form B89.4.1 Volume length repeatability test. For example, the B89.4.1 Volume component will accept the expression 5/750 but this expression cannot be used for the 10360 E0 specification limit.

Examples of the different length expressions that can be used are shown in the following table.

Length Expression Examples:

Example	*Description*	*Comment*
5.0/700	Allowed um variation in length when using an artifact that is 700 mm in length.	Typical format for an ASME B89.4.1 length repeatability specification with a specific length of ball bar. This format can only be used for the ASME B89.4.1 length repeatability specification.
2.0+3.0L/700	Allowed um variation in length when using a test artifact of length L in mm.	Typical format for ISO/IEC 10360-2 E0test.
2.0+L/250	Allowed um variation in length when using a test artifact of length L in mm with 1 um per L implied.	Typical format for ISO/IEC 10360-2 E0 test.
2.0+3.0L/700 | 5.0	Allowed um variation in length when using a test artifact of length L in mm with a fixed upper limit.	Typical format for ISO/IEC 10360-2 E0 test with a fixed upper limit.
2.0+L/250 | 5.0	Allowed um variation in length when using a test artifact of length L in mm with a fixed upper limit with 1 um per L implied.	Typical format for ISO/IEC 10360-2 E0 test with a fixed upper limit.
(5.0+0.05Td)/700	Allowed um variation in length when using an artifact that is 700 mm in length. The variable Td represents the deviation in temperature from 20 °C	Typical format for an ASME B89.4.1 length repeatability specification with a specific length of ball bar. The tolerance increases based on the deviation in temperature from 20 °C. This format can only be used for the ASME B89.4.1 length repeatability specification.
5.0+0.05Td+(5.0+0.2Td)L/700	Allowed um variation in length when using an artifact of length L in mm. The variable Td represents the deviation in temperature from 20 °C.	Typical format for ISO/IEC 10360-2 E0 test. The tolerance increases based on the deviation in temperature from 20 °C.

The specification editor expects all limit values in um and length values in mm. No other formats other than those from the above examples will be accepted.

Entry Names

The names for the *Make*, *Model*, and *Option* are checked to ensure certain characters are not used that could result in problems with either the SQL database data or the format of the exported CSV data. The characters ' ” % * [ ] ^ \ / , : , if used in any of the text entries, are automatically deleted.

Problematic characters can be handled by substituting with a unique and safe sequence in a manor that is similar to how HTML or XML handle < or > characters and may be added in a future version of the CMM Specification utility if deemed necessary.

Specification Limits

The specification limits converts a user provided artifact length and actual temperature into single value limits for the various supported standards. When running the performance tests of a CMM it is often desirable to know the real limit values without the effort of manually calculating it based on specifications expressions. Illustration 6 shows an example of specifications with both length and temperature components where illustration 7 shows the resulting limits at a specific artifact length and ambient temperature.

Specifications:

Standard	Component	Expression	Source	Description
▾ 10360				
	E0	3.5+0.05Td+(3.0+0.20Td)L/1000	MFG	Maximum length error
	R0	3.5	MFG	Maximum length variation for E0
	E150	3.5+0.05Td+(3.0+0.20Td)L/1000	EST	Maximum length error with probe offset
	Rpt	2.0	EST	Maximum sphere position variation
▾ B89.4.1				
	Repeat	2.0	MFG	Maximum sphere position variation
	Volume	(10.0+0.30Td)/550	MFG	Maximum length variation of a ballbar
▾ VDIVDE_2617				
	U3	3.5+0.05Td+(3.0+0.20Td)L/1000	EST	Maximum length error in three axis
▾ CMMA				
	M	3.5+0.05Td+(3.0+0.20Td)L/1000	EST	Maximum length measurement error
	Repeat	3.5	EST	Maximum length variation error

Illustration 6: Specification example using temperature and length dependent components.

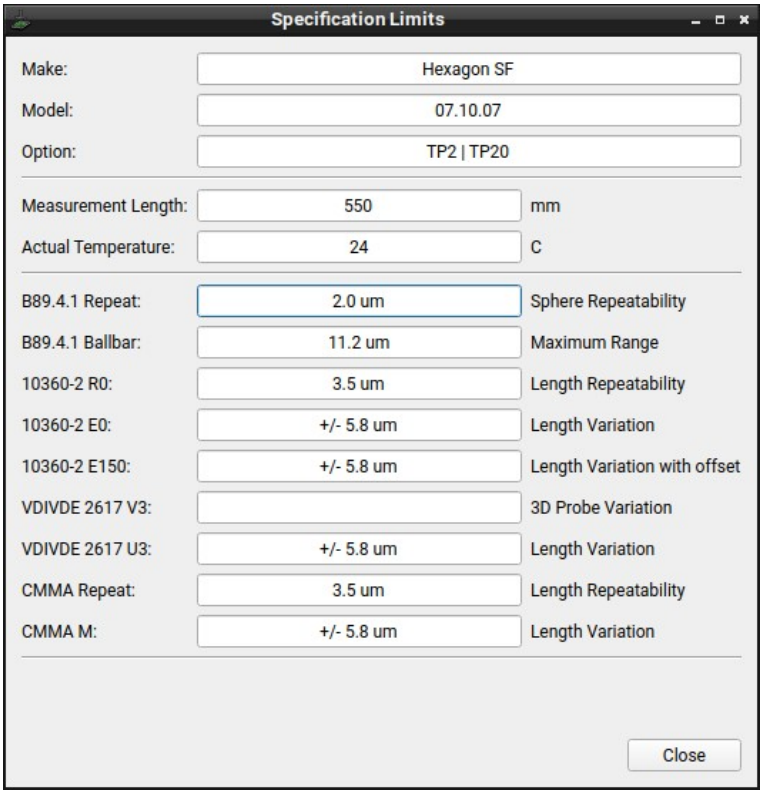


Illustration 7: Specification limits calculated for a length in an environment at the specified temperature.

Limit Calculation Example

Using the information shown in illustration 7 and specifications from illustration 6 the calculated limits would be the following:

```
ASME B89.4.1:1997 Ballbar:
   =(10 + 0.3Td)
   = 10 + 0.3 * (24-20)
   = 11.2 um

ISO/IEC 10360-2 E0 or E150:
   = 3.5 + 0.05Td + (3 + 0.2Td)L / 1000
   = 3.5 + 0.05 * (24-20) + (3 + 0.2 * (24-20))L / 1000
   = 3.5 + 0.2 + (3 + 0.8) * 550 / 1000
   = 5.79 um
```

Specification Estimation

The estimation of specifications is done based on the similarity of the tests between standards or the interpretation of the meaning of the specific test and what the equivalent would be in other similar tests. There are usually subtle differences between the tests defined by the different standards which may results in the estimation being a little off but, where possible, these differences are taken into account.

One example of a similar set of measurement tests is 10360 Pftu as compared to the VDIVDE

2617 V3 three axis probing. The Pftu test consists of 25 defined points measured on half a precision sphere reporting the form error from the least squares best fit where the V3 test consists of 50 equally distributed points on one half of a precision sphere reporting the form error from the least squares best fit. For estimating specifications the Pftu and V3 tests would be considered identical as they both essentially measure and report the same way.

Conversion Table:

Standard In	*Component*	*Standard Out*	*Component*	*Comment*
10360	Rpt	B89.4.1	Repeat	
		CMMA	Repeat	Value doubled. Note 1
	R0	CMMA	Repeat	
		B89.4.1	Repeat	Value reduced by half. Note 1
	Pftu	VDIVDE_2617	V3	
	E0/E150	B89.4.1	Volume	Expression components doubled. Note 2
		VDIVDE_2617	U3	
		CMMA	M	
B89.4.1	Repeat	10360	Rpt	
		10360	R0	Value doubled. Note 1
		CMMA	Repeat	Value doubled. Note 1
	Volume	10360	E0/E150	Expression components reduced by half. Note 2, Note 3
		VDIVDE_2617	U3	Expression components reduced by half. Note 2, Note 3
		CMMA	M	Expression components reduced by half. Note 2, Note 3
VDIVDE_2617	V3	10360	Pftu	
	U3	10360	E0/E150	
		B89.4.1	Volume	Expression components doubled. Note 2
		CMMA	M	
CMMA	Repeat	B89.4.1	Repeat	Value reduced by half. Note 1
		10360	R0	
	M	10360	E0/E150	
		B89.4.1	Volume	Expression components doubled. Note 2
		VDIVDE_2617	U3	

Note 1 – Conversion Between Sphere and Length Repeatability

Conversion of values such as CMMA Repeat to B89.4.1 Repeat or the reverse is done by doubling or halving the value. The B89.4.1 Repeat is the range of an axis for the repeated measurement of a four point sphere where CMMA Repeat is the range of measurement lengths along a single axis. The ratio between these two limits is assumed to be 2:1.

Note 2 – Conversion Between Range and Tolerance Expressions

Conversion of range expressions such as B89.4.1 Volume to 10360 E0 or the reverse is done by doubling or halving the expression values. The result of a B89 ball bar test is the total range of measured lengths where the 10360 E0 result is the positive or negative deviation from a nominal length. For example, if the B89.4.1 Volume tolerance is 5+5L/1000 um the equivalent 10360 E0 tolerance would be 2.5+2.5L/1000 so, for a length of 1000 mm, the B89.4.1 Volume tolerance would be 10 um where the 10360 E0 tolerance would be +/- 5 um.

Note 3 – Conversion From B89.4.1 Short Form Volume Expressions

Often B89.4.1 Volume tolerances are shown in the form A/B where A is the tolerance and B is the length of the ball bar. To convert the short form expression into a standard expression such as 10360 E0 it is necessary to include the B89.4.1 Repeat tolerance for the first term of the target expression. For example, if the B89.4.1 Volume tolerance is 10/750 um and the B89.4.1 Repeat tolerance is 3 um the equivalent 10360 E0 tolerance would be 3+5L/750 um. Since expressions such as the 10360 E0 is a plus / minus limit the short form expression is reduced by half. The conversion between sphere repeatability and single axis length measurement is still a 2:1 as described in note 1 which results in the identical first term value.

The order the specifications are estimated is based on the order of the specification types defined in the SQL database. The default order is 10360, B89.4.1, VDIVDE_2617, and finally CMMA. Once an estimated standard is created it will not be replaced so, in the case of overlapping estimations, the first one created is always used. Future versions of the CMM Specification utility may assign a priority level to the different components to ensure the most suitable estimations are always used regardless of the estimation order.

Importing and Exporting Specifications

The specifications can be exported from the SQL database to a CSV file or imported from a similarly formatted file as needed. The two goals for this was to allow conversion to other software and provide an easily accessible backup. Data imported from a CSV file will be combined with existing data allowing CSV files from various sources to be merged if needed.

The exported data only contains non-estimated entries and is further optimized by not including components from standards that are empty in order to keep the resulting file size as small as possible. If there are changes or updates to the specification estimation routines one method to have an existing database updated is to simply export and re-import everything.

CMM Specification CSV Format

Example:

```
CMMSpecificationsDatabase:Version=1:Format=CSV

IMS Impact,1000,TP2 | TP20,10360,Pftu:0.0031,E0:0.0027+0.0010L/250
```

```
IMS Impact,1500,TP2 | TP20,10360,Pftu:0.0031,E0:0.0030+0.0010L/250
IMS Merlin,11.22.10,TP2 | TP20,B89.4.1,Volume:0.0104/610
IMS Merlin,11.22.10,TP2 | TP20,CMMA,M:0.0050+0.0010L/300
…
```

Comments:

- First line must be *CMMSpecificationsDatabase:Version=1:Format=CSV*
- Each data line in the file must contain a minimum of 4 comma separated entries consisting of the make, model, option, and standard followed by the component entries.
- Each component entry consists of the name and expression separated by a colon.
- Comment lines begin with the hash symbol (#).

Line Entry:

Make, Model, Option, Standard, Component:Expression, Component:Expression, ...

Where:

Make = Name for the CMM Make
Model = Name for the CMM Model
Option = Name for the CMM Option
Standard = Name of the specification standard
Component = Name of the specification standard component
Expression = Value or expression assigned to the specification standard component.

Specification Output

The specifications for the selected CMM *Make*, *Model*, and *Option* can be output to a PDF file in a presentable format. The primary purpose of this is to create a file that can be sent as part of a quotation for calibration. The end user usually knows the capability of their equipment and may provide feedback if some items are incorrect. Ultimately providing this information to the end user prior to a calibration establishes an understanding of the expected capability of the equipment for the various tests that can be performed on the CMM.

Coordinate Measuring Machine Specifications

Make: BnS Chameleon
Model: 12.20.10
Option: TP200

Component	Expression	Source	Description
ASME B89.4.10360, ISO/IEC 10360			
E0	2.9+1.0L/310	MFG	Maximum length error
Ts_Max	22.00 C	MFG	Maximum volume temperature celsius
Ts_Min	18.00 C	MFG	Minimum volume temperature celsius
E150	2.9+1.0L/310	EST	Maximum length error with probe offset
Rpt	3.1	EST	Maximum sphere position variation
R0	6.2	EST	Maximum length variation for E0
Pftu	2.1	EST	Maximum probe form error
VDIVDE_2617			
U3	2.9+3.2L/1000	MFG	Maximum length error in three axis
V3	2.1	MFG	Maximum probe error in three axis
ASME B89.4.1			
Repeat	3.1	MFG	Maximum sphere position variation
Volume	11.5/800	MFG	Maximum length variation of a ballbar
CMMA			
M	2.9+3.2L/1000	MFG	Maximum length measurement error
Repeat	5.4	MFG	Maximum length variation error

Legend

L	Length in mm
Td	Temperature deviation from standard reference in Celsius
MFG	Specification provided by manufacturer
EST	Estimated specification derived from manufacturer specifications

All expression results in um (micrometers) unless otherwise specified.

Illustration 8: Specification output example.

Revision History

Date	*Version*	*Changes*
Feb 25, 2023	1.0	New Program
Jun 21, 2024	1.1	[bug fix] Expression logic problem with temperature values. Added ability to import Calibration Workspace XML specification files.