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Title: TA-55 Hot CMM Calibration Tolerance Analysis (U)

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Report

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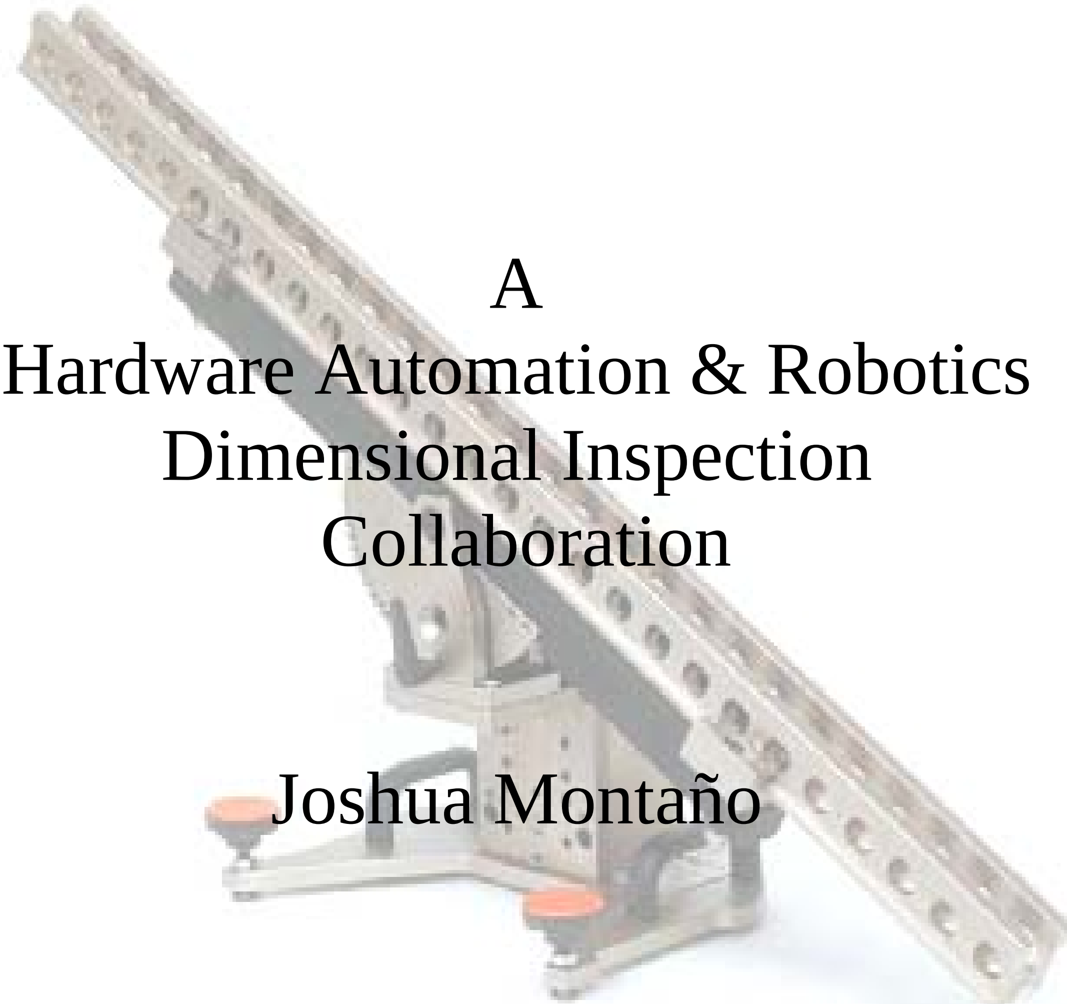

A
Hardware Automation & Robotics
Dimensional Inspection
Collaboration

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Abstract

The Hot Coordinate Measuring Machine (CMM), a Brown and Sharpe Xcel 765, has specifications listed by the manufacture of 4.5 + L/250 μm for volumetric performance, 3.5 μm for probing and 4.5 μm for scanning. An upgrade was performed on the machine increasing its performance capability. This document reviews calibration data gathered after the upgrade over a five year period (2005 – 2010) and recommends a new specification of 3.0 + L/250 μm for size, 3.3 μm for probing, and 4.3 μm for scanning. The new equations are an approximate 30% increase in accuracy for size and approximately 5% increase for probing and scanning.

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1.0 Introduction

This report was created to document the improved performance of the Hot CMM post upgrade. Hardware improvements have demonstrated an enhanced capability worthy of an improved performance specification.

1.1 Hot CMM Upgrade

In fiscal year 2003 an upgrade project was initiated to address issues associated with the end of design-life and reliability of the equipment [1]. The project included a new B3C-LC controller, reconditioned bridge, new motors and drive system, new Global Image type air bearings, Renishaw tape scales and encoders, a PH10MQ probe head, Quindos 6 was installed and a new glove box enclosure was also implemented [2].

1.2 Performance Specification Calibration Tolerance Limits

In 2005 and years prior, Los Alamos National laboratory (LANL) used the American National Standards Institute (ANSI) / American Society of Mechanical Engineers (ASME) B89 standard to certify CMM's [3,4]. By mid-2005 (and post Hot CMM upgrade) the Laboratory began using the International Organization for Standardization (ISO) 10360 standard to certify CMM's [5,6,7].

Calibration tolerance limits specified by the manufacturer for volumetric length is listed as 4.5 + L/250 µm (with L in mm) [8]. In addition the LANL Standards and Calibration Laboratory (S&CL) adds an additional 25% as an allowance for environmental conditions, drift, wear, and historical data.

Table 1. Hot CMM Calibration Tolerance Limits

Test, µm	Manufacture's Specification	S&CL Interval Tolerance
Accuracy (MPE_E)	4.5 + L/250 (L in mm)	5.6 + L/250 (L in mm)
Volumetric Probing (MPE_P)	3.5	4.4
Scanning ($MPE_{THN, TLN, TLP, THP}$)	N/A (4.5 from customer)	5.6

2.0 Data Analysis

There were three main steps taken in the data analysis. First gather all the available information, second check if the data was a normal data set, and third use some basic statistics to justify a revised tolerance specification.

2.1 Data Sets

The data sets used in this report can be found on the S&CL website and are listed in the table below. The ten calibration certificates produced a sample size of more than 1000 data points.

Table 2. Post Upgrade Hot CMM Calibration Data Sets

Calibration Date	Website Data Location
September 15, 2005	http://stdscal.lanl.gov/s&cl_images/05/img/024484_C.pdf
January 11, 2006	http://stdscal.lanl.gov/s&cl_images/06/img/024484_A.pdf
August 15, 2006	http://stdscal.lanl.gov/s&cl_images/06/img/024484_B.pdf
January 5, 2007	http://stdscal.lanl.gov/s&cl_images/07/img/024484_A.pdf
December 21, 2007	http://stdscal.lanl.gov/s&cl_images/07/img/024484_B.pdf
February 7, 2008	http://stdscal.lanl.gov/s&cl_images/08/img/024484_A.pdf
August 7, 2008	http://stdscal.lanl.gov/s&cl_images/08/img/024484_B.pdf
July 30, 2009	http://stdscal.lanl.gov/s&cl_images/09/img/024484_A.pdf
December 15, 2009	http://stdscal.lanl.gov/s&cl_images/09/img/024484_B.pdf
October 26, 2010	http://stdscal.lanl.gov/s&cl_images/10/img/024484_A.pdf

2.2 Normality

There are different ways of testing a data set for normality. One of the easiest and most commonly used is a graphical representation of a data set in a histogram format and comparison against a Gaussian function or "bell curve". Using the equations 1-3 and in Figure 1 below, the data appears to follow a normal distribution [9].

$$\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \qquad (1)$$

With,

$$\mu = \frac{1}{n}\sum_{i=1}^{n} X = \text{-0.00005 mm} \qquad (2)$$

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} = 0.00157 \text{ mm} \qquad (3)$$

Note: 2σ or 95% confidence = ± 0.0031 mm

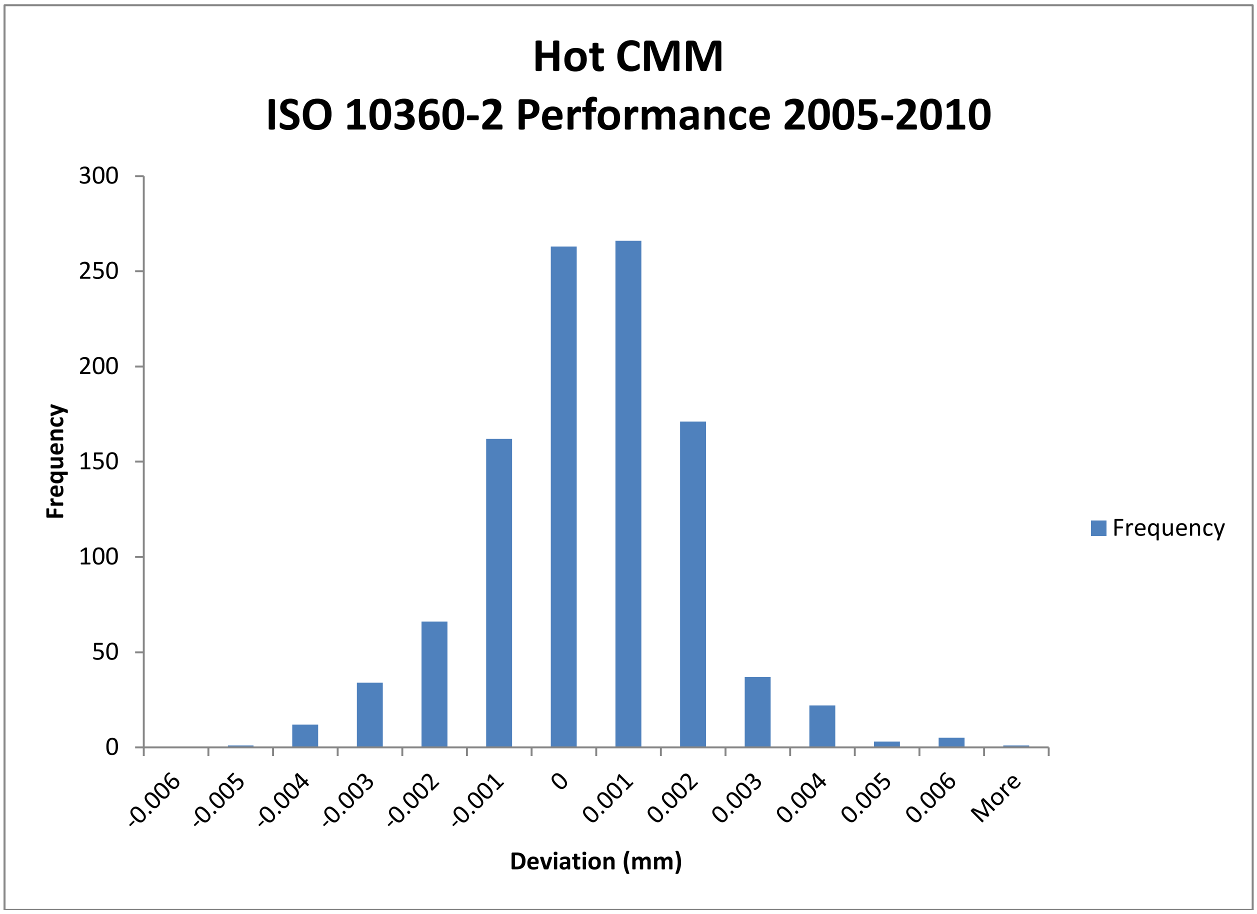

Figure 1. ISO 10360-2 Hot CMM Performance Histogram (2005-2010)

2.3 Analysis by Length

The last step was to overlay data by length from each certification direction (see Figure 2) and calculate a 95% confidence interval. The result is an estimate of the calibration tolerance.

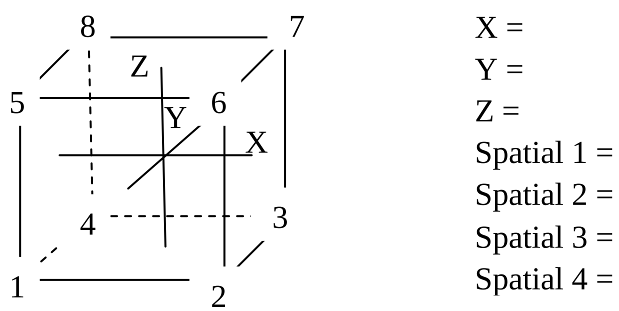

Figure 2. Spatial Representation of Hot CMM Data Collection Strategy

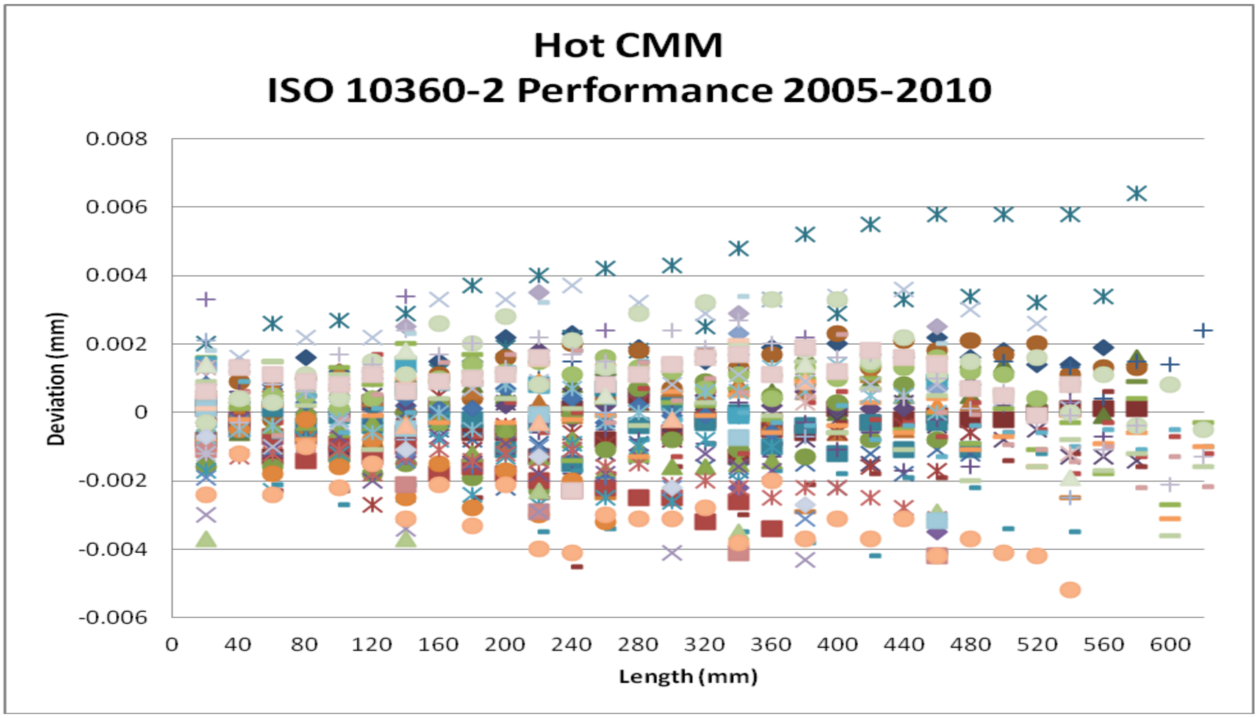

Figure 3. ISO 10360-2 Hot CMM Performance Overlay (by length, 2005-2010)

Average and standard deviation were calculated at each length to find the upper and lower 95% confidence interval enclosing the data set.

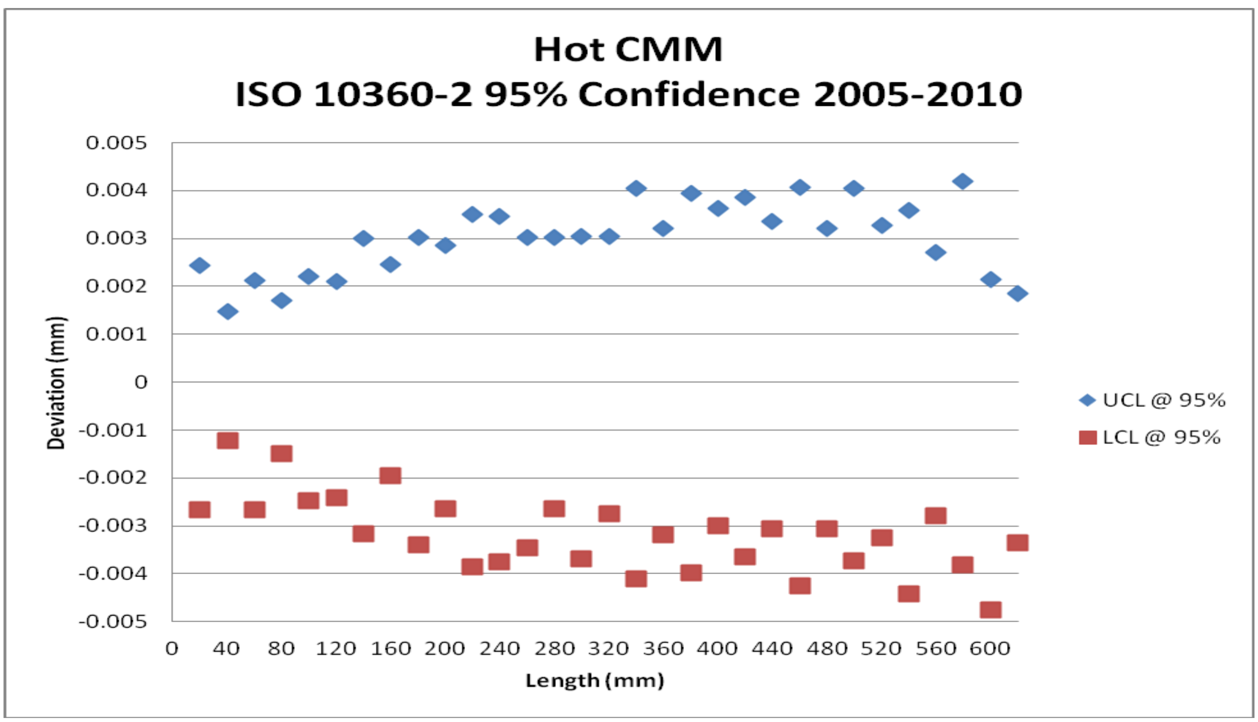

Figure 4. ISO 10360-2 Hot CMM Performance using 95% Confidence (2005-2010)

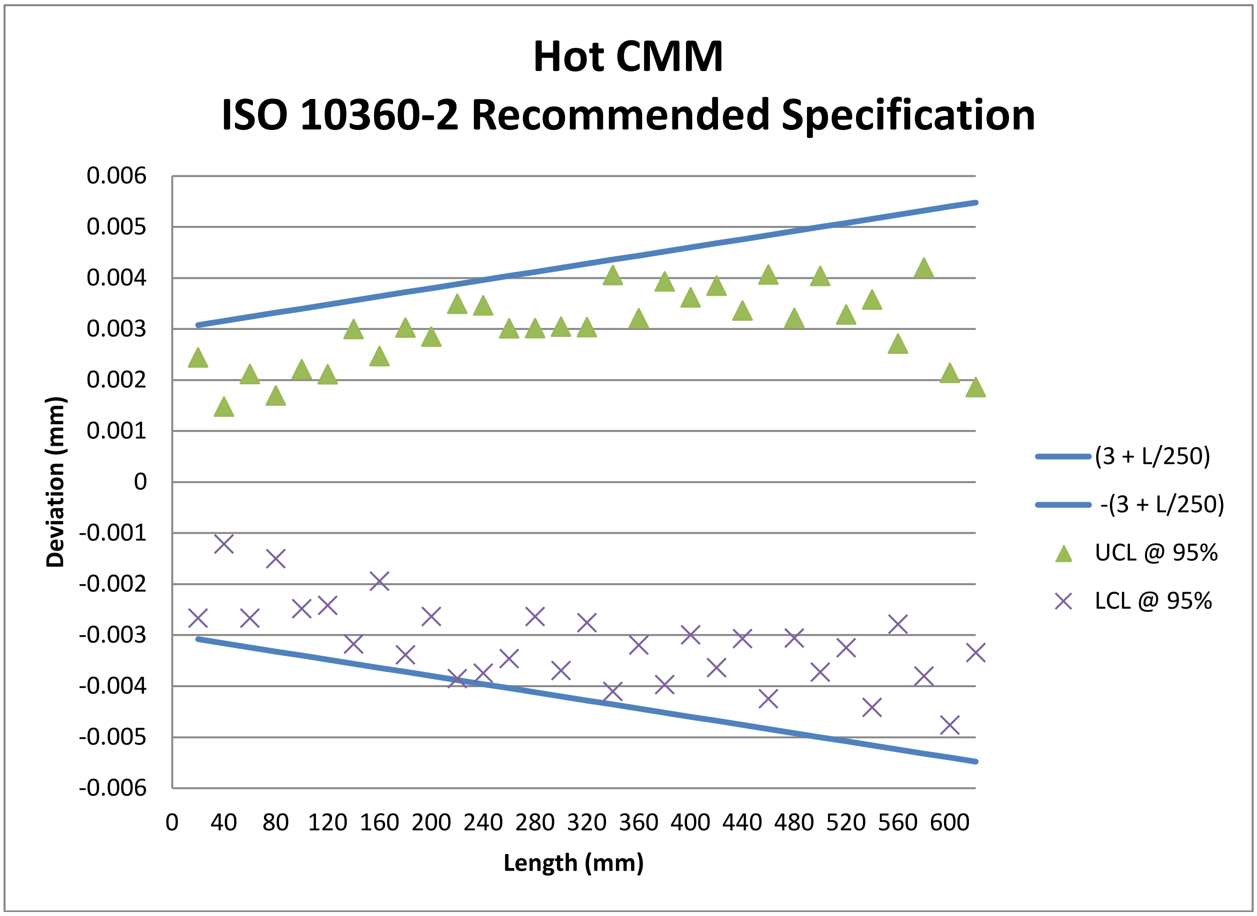

Figure 5. ISO 10360-2 Hot CMM Recommended Specification

The same approach was also taken for 10360-4, probing and scanning. The average plus two standard deviations ($\mu + 2\sigma$) produced results of 3.3 µm for probing and 4.3 µm for scanning.

3.0 Conclusions

In conclusion, the data gathered subsequent to the Hot CMM upgrade over a five year period strongly supports an accuracy better than the original manufacture's specifications. It is the recommendation of this report to consider modifying the calibration tolerance limits listed in the Calibration Requirements document to those listed in Table 3 below [10].

Table 3. Post Upgrade Hot CMM Recommended Specifications

Test, µm	Manufacture's Specification	Recommended Interval Tolerance	Recommended S&CL Interval Tolerance
Accuracy (MPE_E)	4.5 + L/250 (L in mm)	3.0 + L/250 (L in mm)	3.8 + L/250 (L in mm)
Volumetric Probing (MPE_P)	3.5	3.3	4.1
Scanning ($MPE_{THN, TLN, TLP, THP}$)	N/A (4.5 from customer)	4.3	5.4

4.0 Future Work Recommendations

It is recommended that a detailed review of all subsequent Hot CMM calibrations be completed and added to the trends shown in this report. While past records indicate that the machine was stable and operating above manufacture's specifications it does not reduce the uncertainty of the current condition. The incident discussed in *"Anatomy of an Incident: TA-55 Hot CMM (U)"*, significantly changed the machine geometry and it will take time to evaluate if the machine is still stable [11]. It is also recommended that calibration intervals be evaluated.

Two upgrades that should also be considered for improved accuracy are the probe head and firmware. New technology exists providing the opportunity for more accuracy in the SP25 probe head. Also the B3C-LC controller is currently running firmware version 23 while the manufacturer has since released 20 updates and is running version 43.

5.0 References

[1] Kautz, D.D., *"Hot CMM Upgrade"*, LALP-05-112, Los Alamos National Laboratory, October 2005

[2] Montaño, J.D., *"Hot CMM Upgrade"*, LANL, IMOG/JOWOG 39, October 2005

[3] "*Methods for Performance Evaluation of Coordinate Measuring Machines"*, ANSI/ASME B89.4.1-1997

[4] *"Calibration Certificate"*, http://stdscal.lanl.gov/s&cl_images/05/img/024484_A.pdf, 024484, Los Alamos National Laboratory, January 2005

[5] *"Geometrical Product Specification (GPS) – Acceptance and reverification test for coordinate measuring machines (CMM) – Part 2: CMMs used for measuring size"*, ISO 10360-2:2000(E), International Standard

[6] *"Geometrical Product Specification (GPS) – Acceptance and reverification test for coordinate measuring machines (CMM) – Part 4: CMMs used in scanning measuring mode"*, ISO 10360-4:2000(E), International Standard

[7] *"Calibration Certificate"*, http://stdscal.lanl.gov/s&cl_images/05/img/024484_C.pdf, 024484, Los Alamos National Laboratory, September 2005

[8] *"Xcel Service Manual"*, 82-90044-1, Brown & Sharpe, 1994

[9] Moore, D.S., *"Introduction to the Practice of Statistics"*, 92-2280, W. H. Freeman and Company, 1993

[10] *"LANL Performance Testing & Calibration Requirements for MQ-2 CMMs"*, 1/2007

[11] Montaño, J.D., *"Anatomy of an Incident: TA-55 Hot CMM (U)"*, LA-UR-12-01216, Los Alamos National Laboratory, March 2012

6.0 Acknowledgements

Special acknowledgements to the many contributors that helped calibrate the Hot CMM over the years. Originally handled by the vendor, LANL now does all of its own certifications. Work coordination between inspectors, engineers, and the Standards and Calibration Laboratory is a large task that successfully gets managed every year to return the Hot CMM back to service.

It should also be noted that these tasks are completed in a radioactive glovebox and in a high hazard facility. Current high visibility projects such as Pit Manufacturing, Enduring Stockpile, Surveillance, and Gemini can all continue to depend on the high quality measurements they need without any significant delay in schedules.

It is the author's hope that this report will improve the quoted accuracy of the machine and that other future collaborative efforts put forth between Hardware Automation & Robotics and Dimensional Inspection will likewise continue to overcome great challenges.

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Maes, Gene	Calibration Coordinator
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Mehlin, Karen	Calibration Coordinator
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Sweeney, Magdalena	S&CL QA Specialist
Tafoya, Pete	Data collection
Vigil, Fidel	Calibration Coordinator

7.0 Appendix: Performance with Original and Proposed Specifications

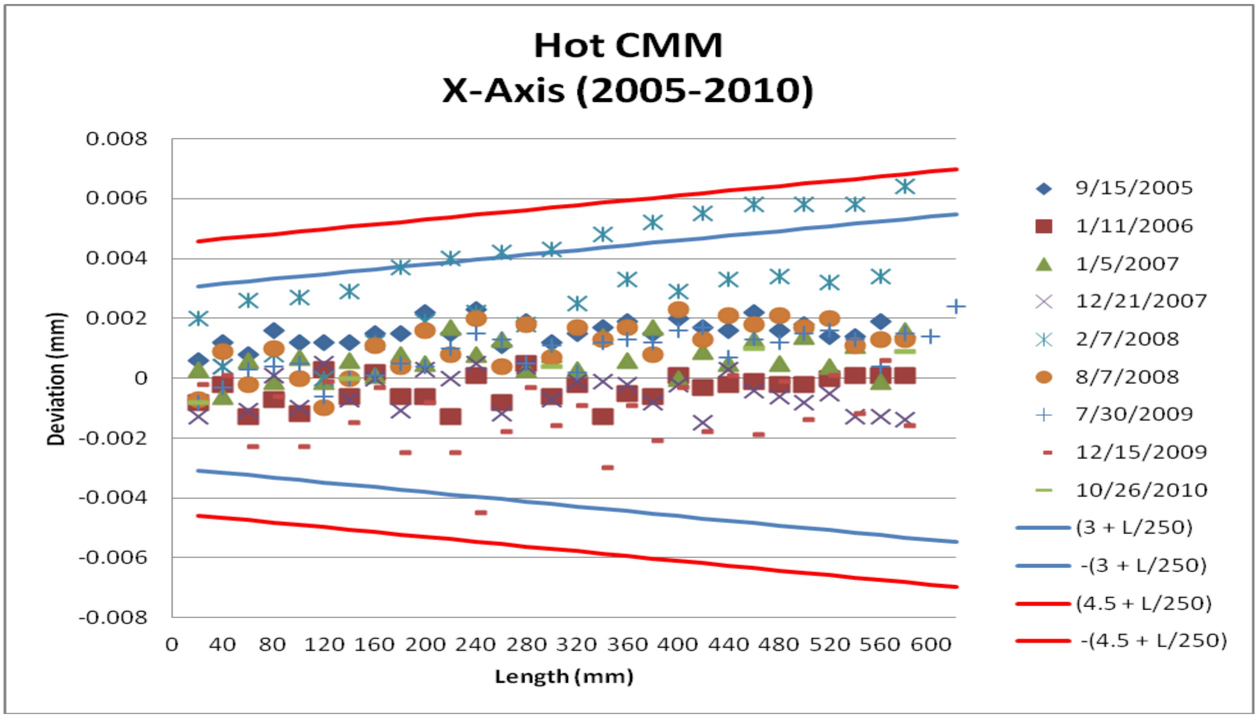

Figure A1. ISO 10360-2 Hot CMM Performance X-Axis (2005-2010)

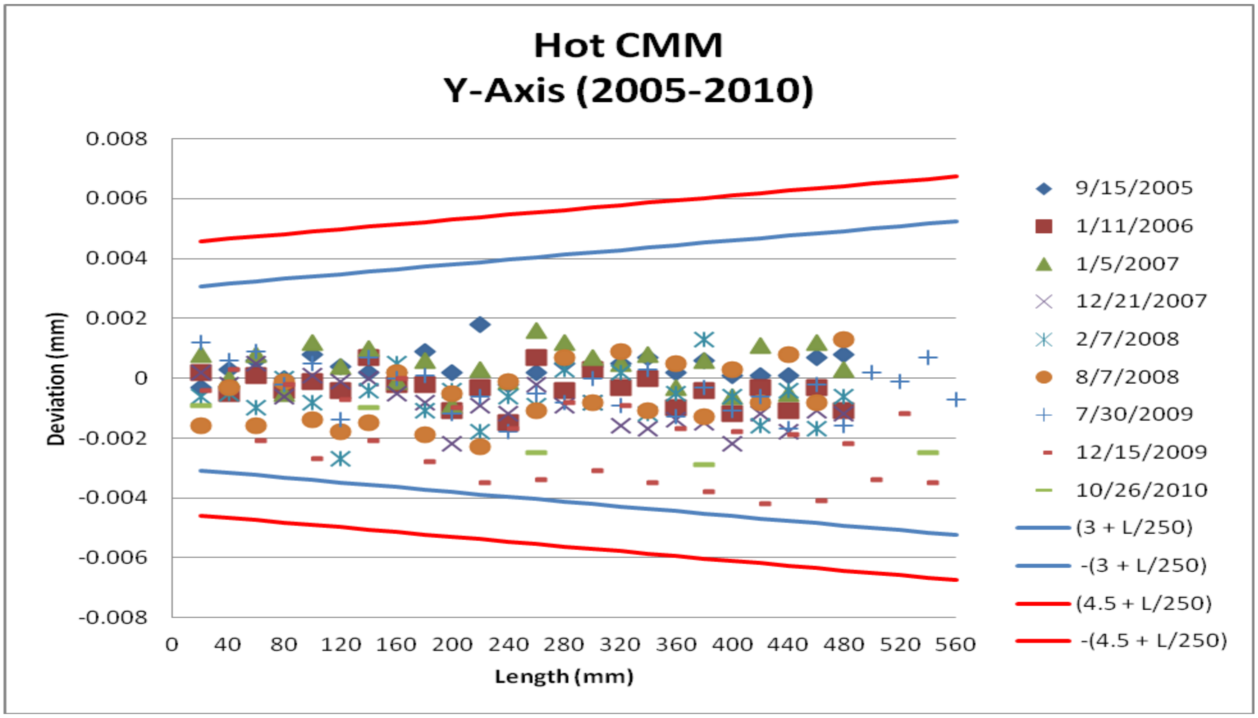

Figure A2. ISO 10360-2 Hot CMM Performance Y-Axis (2005-2010)

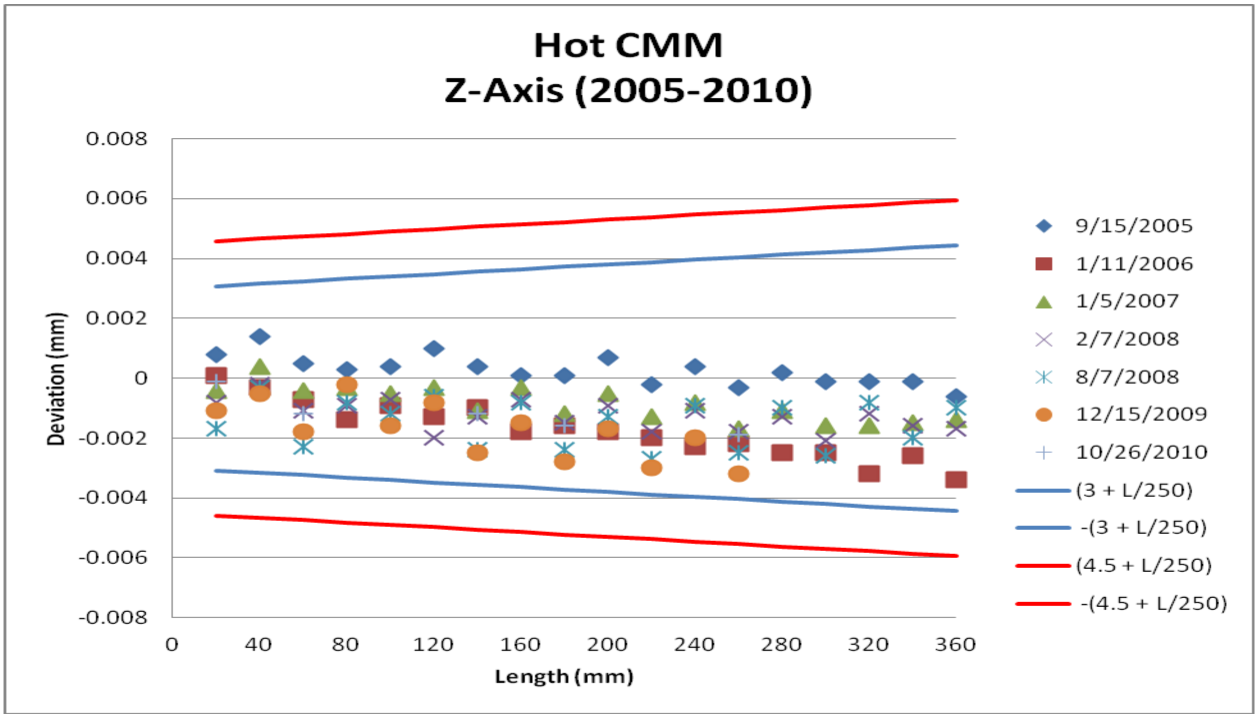

Figure A3. ISO 10360-2 Hot CMM Performance Z-Axis (2005-2010)

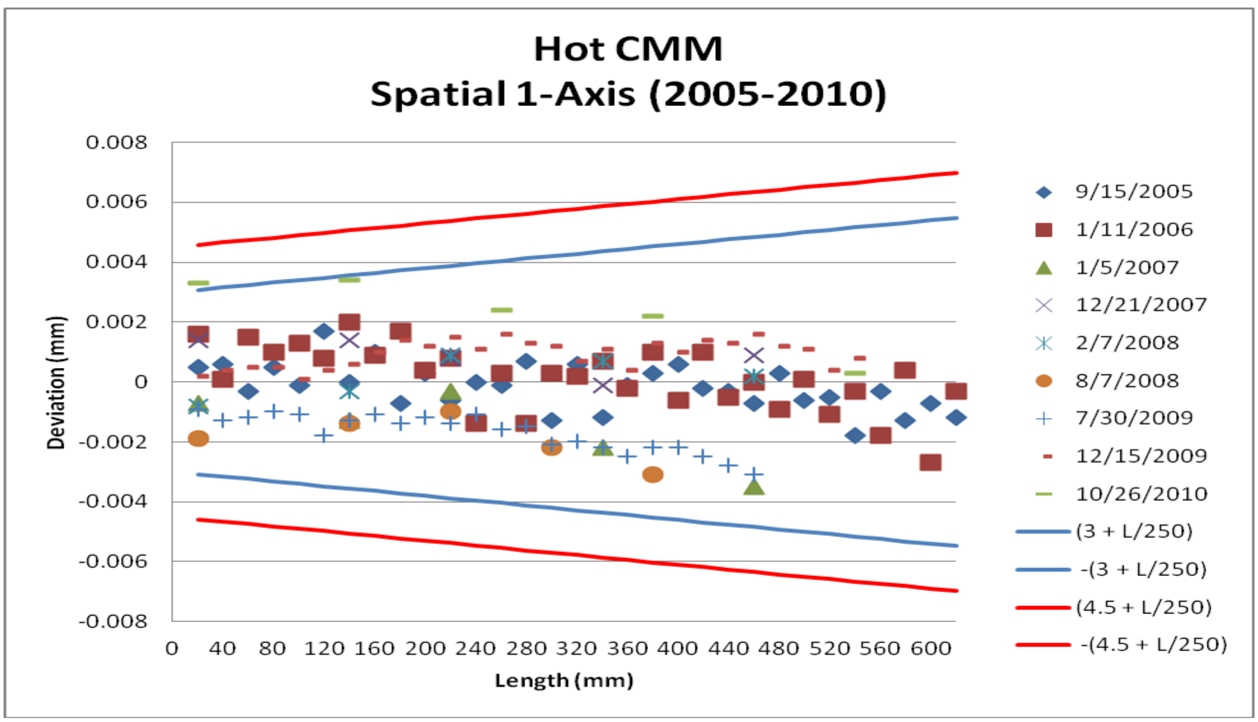

Figure A4. ISO 10360-2 Hot CMM Performance Spatial 1-Axis (2005-2010)

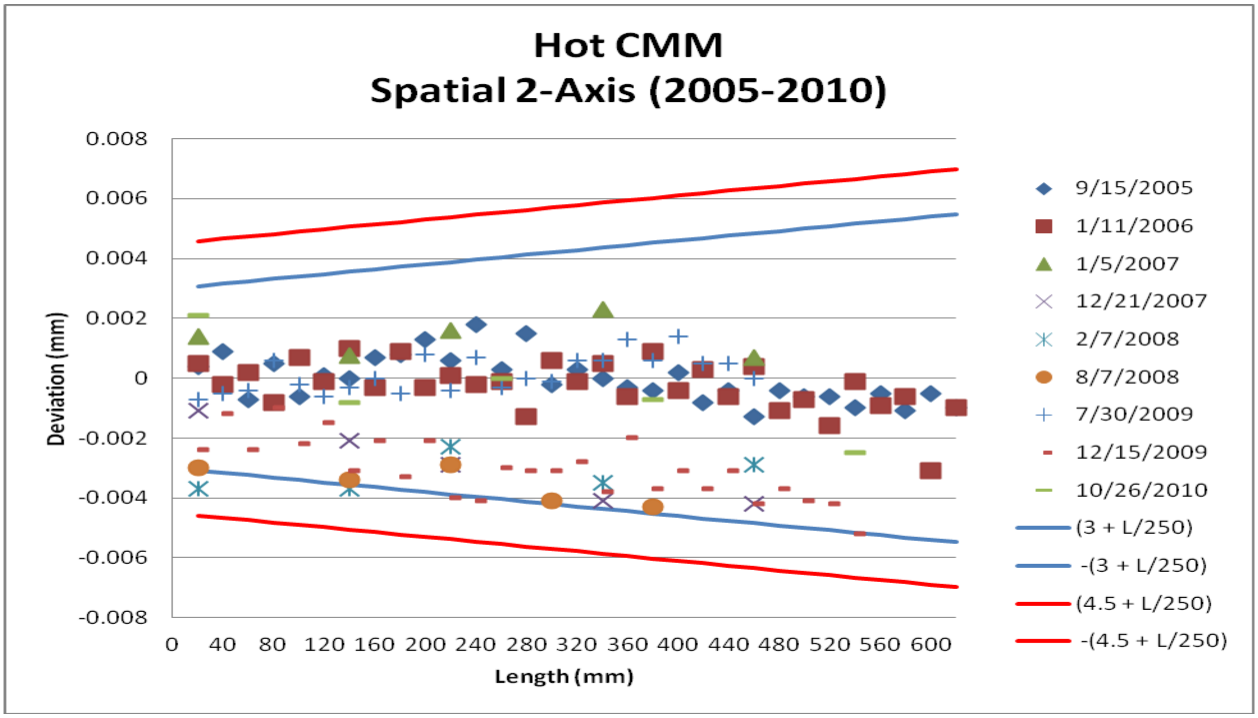

Figure A5. ISO 10360-2 Hot CMM Performance Spatial 2-Axis (2005-2010)

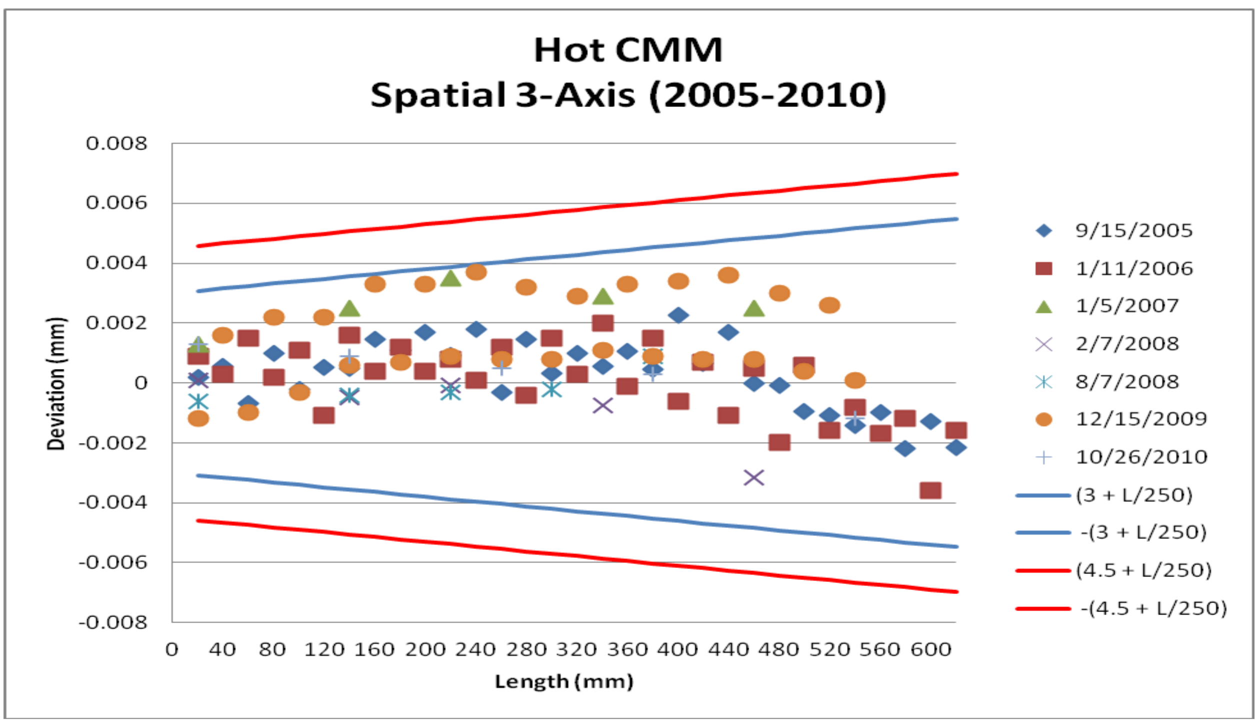

Figure A6. ISO 10360-2 Hot CMM Performance Spatial 3-Axis (2005-2010)

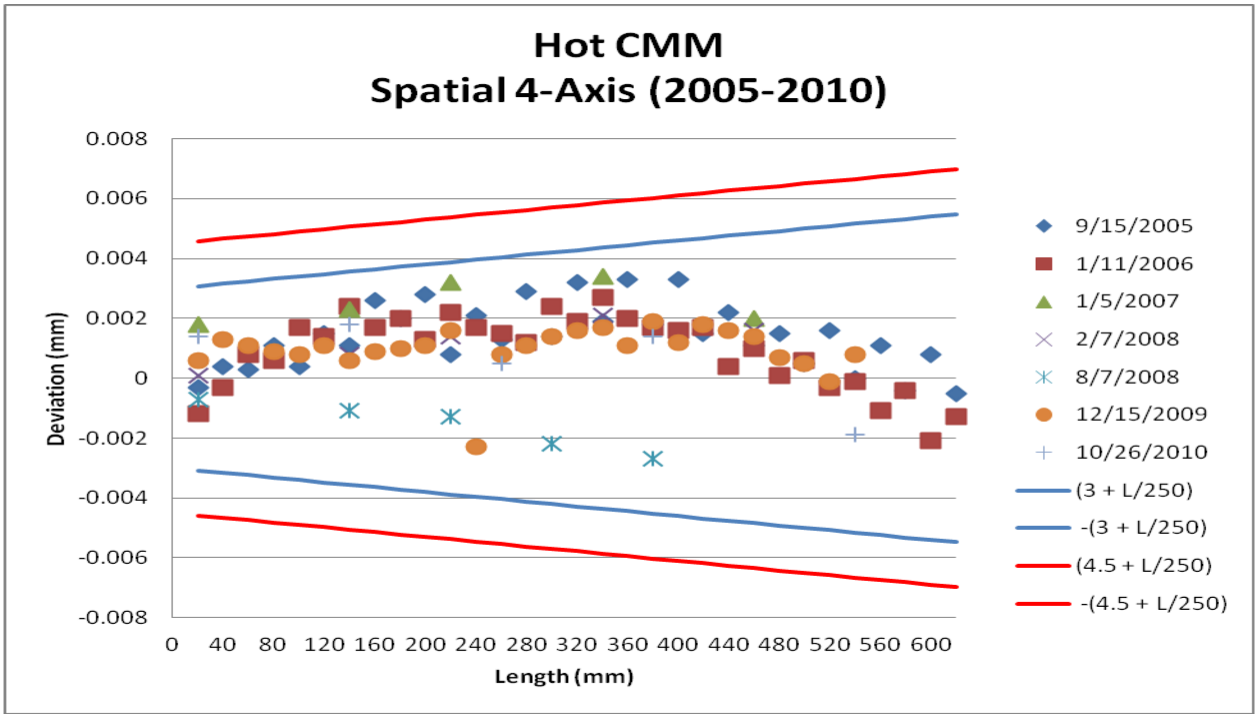

Figure A7. ISO 10360-2 Hot CMM Performance Spatial 4-Axis (2005-2010)