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Initial Evaluation of a Micro-CMM

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Abstract

Sandia National Laboratories has recently acquired an early version of a commercial, micro-CMM. The machine has a work volume of 100×100×100 mm and a published MPE_E of (0.25 +L/666) μm. The hardware and special considerations in the use of such a machine are discussed. Initial results from evaluation of the machine performance show that the machine repeatability is in the 50nm range and that it performs to the published specification level.

1. Introduction

Meso-scale parts are generally defined as being millimeters in scale with feature that have micrometer scale tolerances. Certifiable measurements of complex 3D geometries at that scale are challenging with existing dimensional inspection equipment. A new class of Coordinate Measuring Machines has recently become commercially available. Sandia National Laboratories (SNL) has taken delivery of an early version of one of these systems and is in the process of evaluating it for meso-/micro-scale work.

2. Hardware

The new CMM shown in Figure 1 has a published MPE_E [2] of (0.25 +L/666) μm (where L is the measured displacement in mm) with a measuring volume approximately 100×100×100 mm. The system uses a silicon flexure and strain gauge based stylus system that exerts a force of approximately 0.5mN on the part. Mechanically, it is a novel design with a dual bridge arrangement that minimizes Abbe offsets. That is, all three scales are nearly in line with the probe stylus at all times. The motion is guided by air bearing pads.

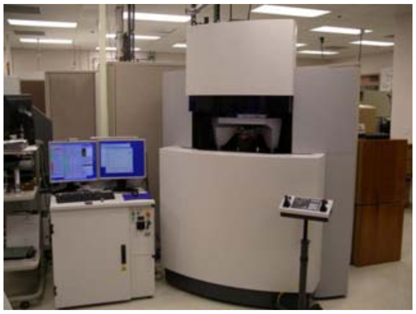

Figure 1. Micro CMM.

Although only tactile measurements are discussed here, the system is capable of integrated tactile and optical measurements with a sensor arrangement shown in Figure 2. The small nature of the parts and tactile sensor make manual driving of the stylus difficult. A high magnification surveillance camera provides visual feedback through a monitor for improved operation.

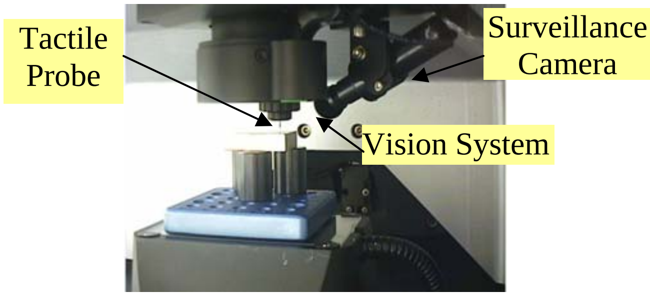

Figure 2. Sensor arrangement.

The tactile sensor itself is also novel and is similar to the device discussed in [1]. Figure 3 shows the sensor that consists of a Silicon chip with slots etched through to create flexures. The shaft and ruby sphere are attached to the chip and provide a lever arm to deflect the flexures. A strain gauge monitors the deflection and provides analog feedback to the controller. The analog characteristic enables surface scanning.

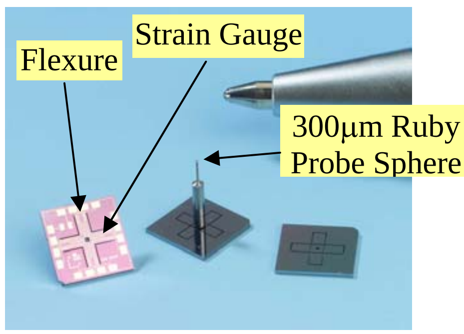

Figure 3. Stylus system.

An important note is that the SNL machine is due for major upgrades in mid-2007. The glass scales will have higher resolution, the motor drives will be improved, part temperature sensors will be integrated, and the machine will be error mapped. The results discussed here are prior to the upgrade.

3. Initial Tests

3.1. Special Gauge Block Certification

A set of 5mm, 10mm, 25mm, 75mm and 100mm Chromium Carbide (Croblox®) gauge blocks are specially calibrated at Sandia National Laboratories Primary Standards Laboratory so that the certified length is at an alternate gauging point 1.5mm down from the top surface (Figure 4). The alternate point is required because the shank length of the stylus does not permit access to the normal gauging point per ASME B89.1.9.

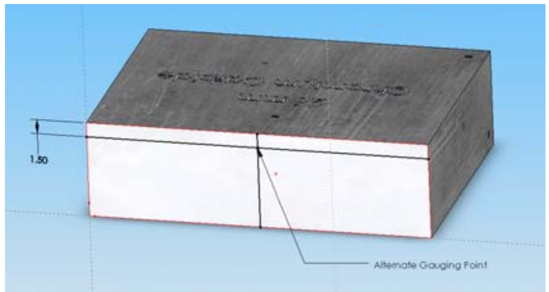

Figure 4. Alternate gauging point.

The calibration is done with a gauge block interferometer that yields k=2 uncertainties in the 50nm-60nm range (Table 1).

Table 1. Gauge Block Certification at Alternate Gauging Point.

Nominal Size (mm)	Correction @ 20C (nm)	Expanded Uncertainty, k=2 (nm)
5	+22	51
10	+15	52
25	+44	53
50	+12	55
75	+31	59
100	+152	63

Chromium Carbide CTE: 8.4×10^{-6} /°C

3.2. Test Results

Measurements of the gauge blocks were taken along the axes of the CMM. The integrated temperature compensation on the machine was not used. Instead, external thermometry was used to monitor the temperature at several locations. Temperature trends over the course of the data acquisition are shown in Figure 5. Corrections to the length were made manually during the data analysis phase using the average temperature during the specific gauge block run and a CTE of 8.4×10^{-6} /°C for the Chromium Carbide.

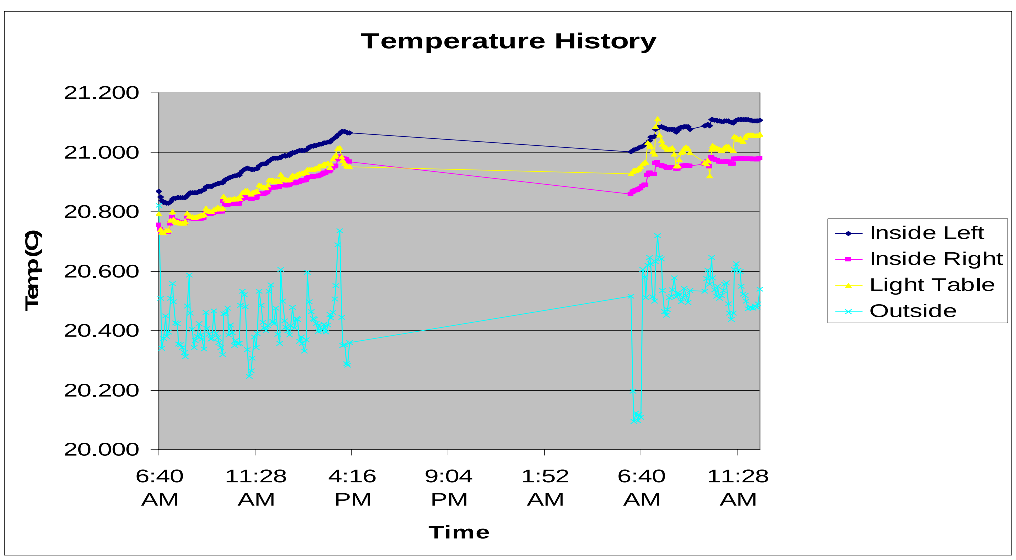

Figure 5. Test temperature history.

The probe sphere was cleaned by manually driving it repeatedly into a pool of spectroscopic grade isopropanol (IPA). At this size scale, the surface tension of the IPA is sufficient to clean the ruby sphere. The gauge blocks were allowed to come to thermal equilibrium for 2 days and cleaned with IPA. Handling times were minimized to reduce thermal disturbances to the gauge blocks.

Figure 6 shows the results for the x-axis data. The gauge block was visually oriented to be in the x- direction. A coordinate system was established using one of the gauging surfaces as the primary datum. Once the coordinate system was established, 30 measurements of the block were taken.

For these measurements the primary contributors to measurement uncertainty are thermal effects and master artifact uncertainty. The relative significance is shown along with the results in Figure 6.

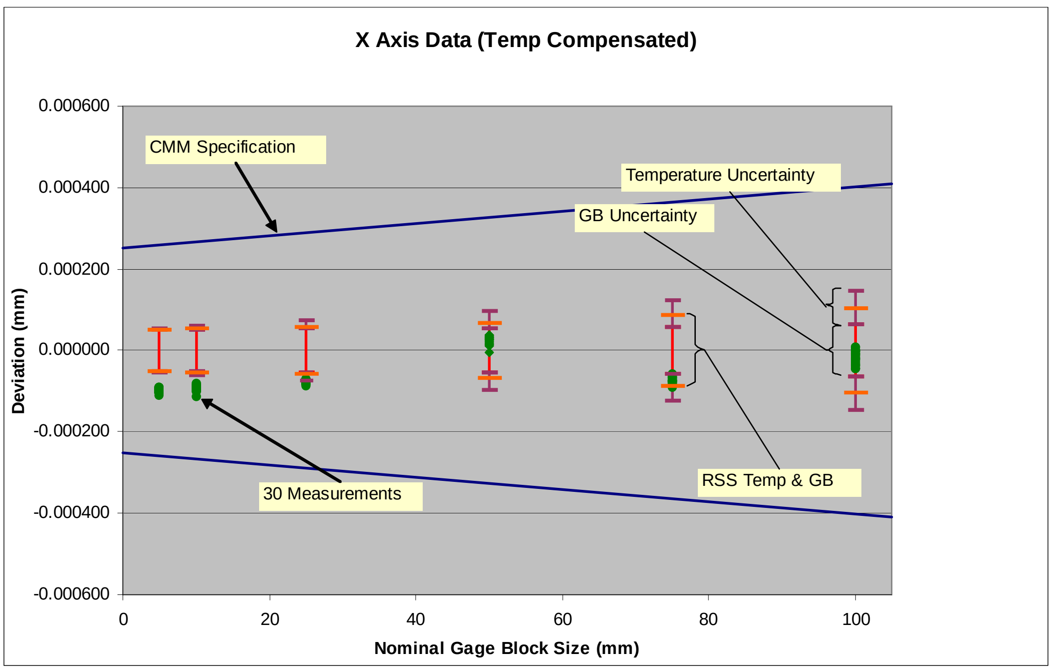

Figure 6. Temperature compensated x-axis results.

The data from Figure 6 is given numerically in Table 2. All of the x-axis data is well within the published specification of the system.

Table 2. Temperature compensated x-axis results.

	5mm	10mm	25mm	50mm	75mm	100mm
Range	21 nm	32	16	45	32	54
Average	-98 nm	-93	-77	25	-74	-17
Std. Dev.	5 nm	6	4	10	7	16
F25 Spec +/-	258 nm	265	288	325	363	400

The y-axis data has a larger distribution than the x-axis data and has one of six length results outside of the published specification. Because the bad result is bracketed by in-tolerance results, the deviation may be explained by a cleanliness problem with that trial.

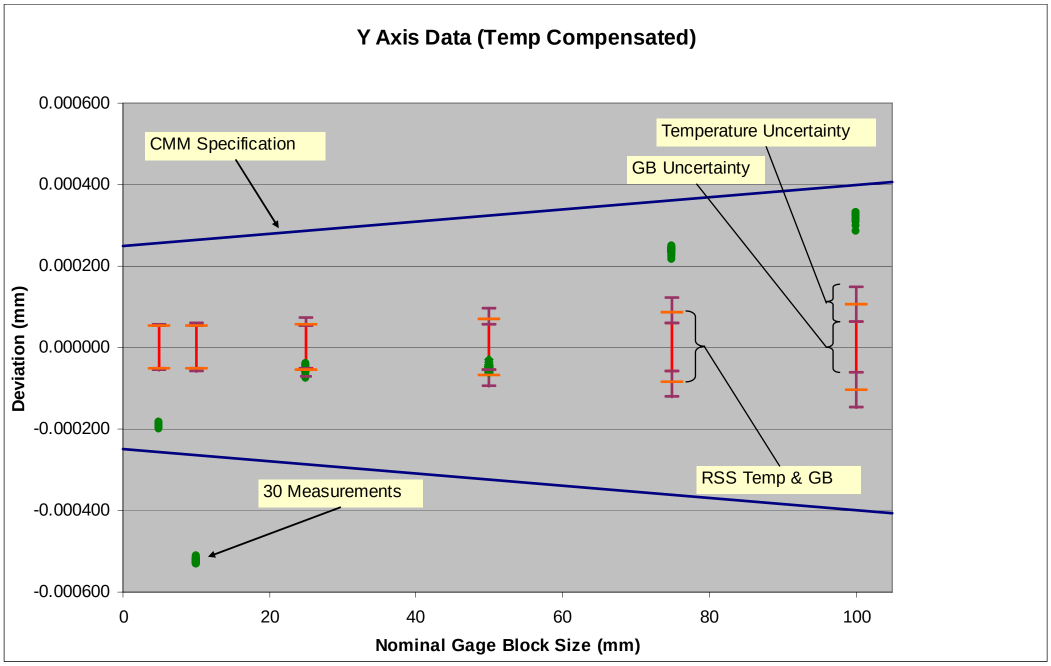

Figure 7. Temperature compensated y-axis data.

Table 3 gives the data in Figure 7 numerically. The bad result is 259nm outside of the specification limit.

Table 3. Temperature Compensated Y-Axis Results.

	5mm	10mm	25mm	50mm	75mm	100mm
Range	17 nm	22	37	33	35	49
Average	191 nm	***-524***	-54	-49	237	320
Std. Dev.	5 nm	5	8	7	7	11
F25 Spec +/-	258 nm	265	288	325	363	400

The stylus system arrangement does not permit measurement of the 50mm, 75mm and 100mm gauge blocks in the z-axis so only the 5mm, 10mm and 25mm blocks were measured. These trials require a deviation from the method used for the x- and y-axes. Instead of probing both sides of the gauge block, the gauge block was wrung to a flat and probings were taken on the flat and the top of the block (the true definition of gauge block length). Results for the z-axis tests are shown graphically in Figure 8.

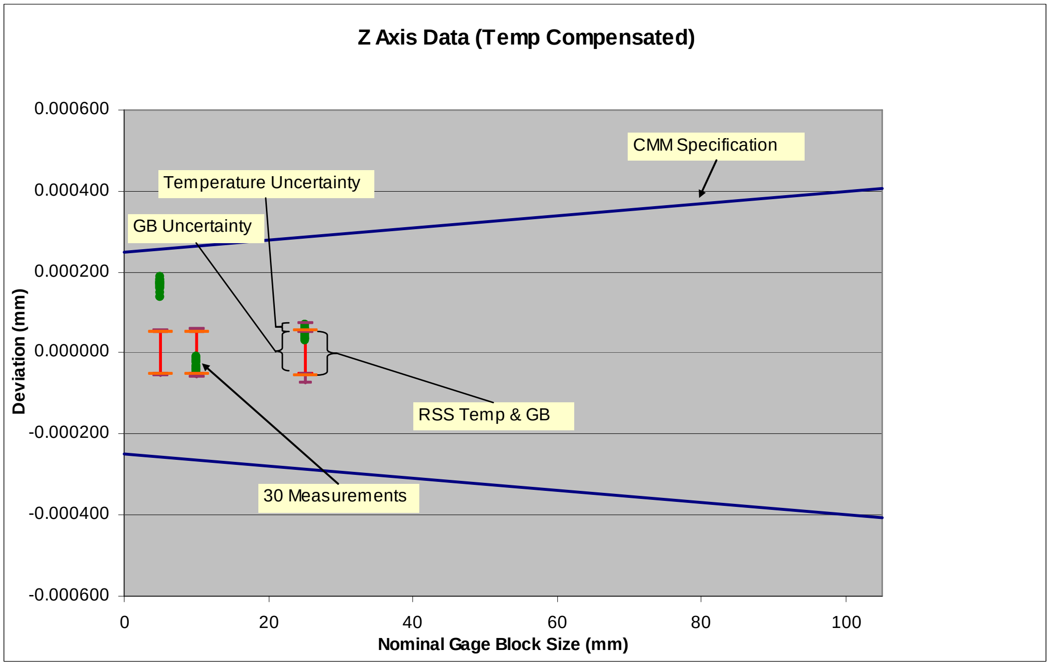

Figure 8. Temperature compensated z-axis data.

The z-axis results are given numerically in Table 4. The three blocks all fall within the published specification for the machine.

Table 4. Temperature compensated z-axis data.

	5mm	10mm	25mm	50mm	75mm	100mm
Range	50 nm	45	41	NA	NA	NA
Average	168 nm	-31	49	NA	NA	NA
Std. Dev.	11 nm	12	12	NA	NA	NA
F25 Spec +/-	258 nm	265	288	325	363	400

Squareness in the xy plane was also assessed with the 75mm gauge block. Although both the measurements given in Table 5 are within the published specification, they can be used to compute a 0.675 arc-second out-of-square condition.

Table 5. Squareness data.

	75mm (+X,+Y)	75mm (-X,+Y)
Range	21 nm	63
Average	-205 nm	286
Std. Dev.	5 nm	14

SNL's existing styli do not allow measurement of the gauge blocks at other orientations required by ISO-10360 style characterization. Styli with a greater probe sphere to shaft diameter ratio will be used to take these measurements when they are available.

4. Important Considerations

Several issues arose as important considerations in the assessment of the new micro-CMM. Because the measurements are on the nanometer level, typical issues of cleanliness and temperature apply. Using compressed air dusters had a deleterious effect on the gauge blocks because of the cooling effect of the expanding gas. The high force of the duster is also not desirable on the stylus. A bulb blower is the preferred method in both cases. Cleaning of the 300μm probe stylus sphere is uniquely done by driving it into a pool of IPA and using the surface tension pull particles from the sphere. Very loose, home-made cotton swabs may also be used with great care if the sphere is particularly dirty. When Acetone and IPA are used to clean either the probe or the part, they should be spectroscopic grade chemicals so that they leave no residue.

The flexure/strain gauge sensor system also requires unique considerations. The linearization of the voltage response as a function of displacement must be done with care. The slope may be determined once for a particular probe when it is installed in the machine (i.e., each time it is installed in the machine). The intercept must be determined frequently (e.g., daily).

5. Conclusions and Future Work

The initial results of the micro-CMM are encouraging. The measured values are within the published specification in all but one case. If the (0.25 +L/666) μm is achieved then acceptance measurements using a 4:1 rule following ASME B89.7.3.1 may be made at the (1 + L/167) μm level for part tolerance.

Once the upgrade is made to the system in mid-2007 a higher accuracy is expected. Although the published specification will not change it may be possible to certify the machine independently at the higher performance level. The vision system will also be activated and its calibration will present challenges. Additionally, relation of the vision coordinate system to the tactile coordinate system will be required. SNL is developing an artifact for that scenario using silicon bulk micromachining. The micro-machined silicon artifact has angles that are intrinsic and form very sharp optical edges. The edges are the result of the intersection of two very good planes so the optical edge may be correlated to a computed edge from two planes. Future work will determine how well the tactile-optical calibration can be.

The system is expected to be primarily used as a tactile inspection system for meso-scale manufacturing operations at SNL. When the upgrade and internal certification are complete it will be deployed for use within the laboratory.

6. References

1. "*Modeling and investigation of the mechanical and electrical characteristics of the silicon 3D-boss microprobe for force and deflection measurements*". Vladimir Nesterov and Uwe Brand 2006 J. Micromech. Microeng. 16 1116-1127
2. ISO 10360-2: 2001, Geometrical Product Specifications (GPS) – Acceptance test and reverification test for CMMs – Part 2: CMMs used for measuring size.