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MEASUREMENT COMPARISONS BETWEEN OPTICAL AND MECHANICAL EDGES FOR A SILICON MICROMACHINED DIMENSIONAL CALIBRATION STANDARD

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ABSTRACT

A mesoscale dimensional artifact based on silicon bulk micromachining fabrication has been developed and manufactured with the intention of evaluating the artifact both on a high precision coordinate measuring machine (CMM) and video-probe based measuring systems. This hybrid artifact has features that can be located by both a touch probe and a video probe system. A key feature is that the physical edge can be located using a touch probe CMM, and this same physical edge can also be located using a video probe.

While video-probe based systems are commonly used to inspect mesoscale mechanical components, a video-probe system's certified accuracy is generally much worse than its repeatability. To solve this problem, an artifact has been developed which can be calibrated using a commercially available high-accuracy tactile system and then be used to calibrate typical production vision-based measurement systems. This allows for error mapping to a higher degree of accuracy than is possible with a typical chrome-on-glass reference artifact.

Details of the designed features and manufacturing process of the hybrid dimensional artifact are given, and a comparison of the designed features to the measured features of the manufactured artifact is presented and discussed.

Measurement results are presented using a meter-scale CMM with submicron measurement uncertainty; an optical CMM with submicron measurement uncertainty; a micro-CMM with submicron measurement uncertainty using three different probes; and a form contour instrument.

INTRODUCTION

Optical CMMs have submicron resolution, but it is difficult to certify their measurement uncertainties at the submicron level. This is due both to problems with specific illumination with optical CMMs [1] and the accuracy of the calibration artifacts used to calibrate optical CMMs [2].

The silicon micromachined artifact design and manufacturing methods were presented in [3], [4], [5]. Feedback from users suggested that micro-CMMs would also benefit from this type of calibration artifact. A second design iteration for fabrication with 150 mm wafers was made. The result of the second design iteration is shown in Figure 1.

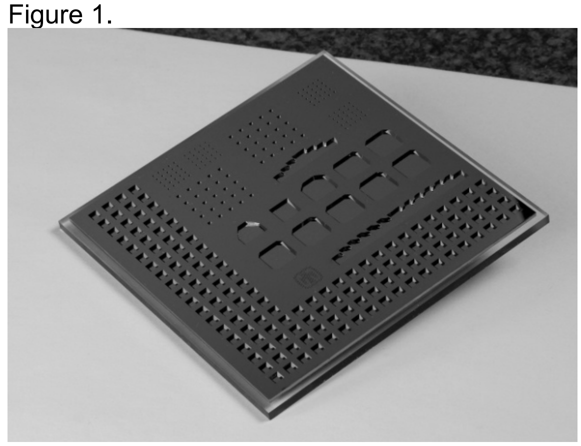

Figure 1. This design was created to operate in a micro-CMM, from [6]

Preliminary results for measurement results of this artifact have been published in [6]. These results compare measurements using a meter scale CMM (Leitz PMM-C Infinity[1], workspace is

[1] Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately describe the experimental procedure. Such identification does not

1.2 m × 1.0 m × 0.6 m) with a capability for expanded measurement uncertainty (coverage factor k=2) of (0.34 + 1.2L) µm (L in m), and an optical CMM (OGP Avant, maximum permissible error (MPE) in 2-D of (1.2+2L) µm (L in m)). As the comparison with the OGP Avant has previously been published, that comparison is not included in this extended abstract.

The artifact was then evaluated on a high accuracy optical CMM (Mitutoyo Ultra Quick Vision, with a 1-D MPE in 1-D of (0.25+L/1000) µm, L in mm), a micro CMM (Mitutoyo M-NanoCoord) with a stated MPE of (0.3+L/1000) µm, L in mm, and a form/contour measuring machine (Mitutoyo Formtracer CS-3100, MPE of (1+10L/1000) µm, L in mm).

MEASUREMENT METHODS

All measurements are made based on the setup illustrated in Figure 2. The top surface (<100> silicon plane) and the West edges of the west-most cavities were used to establish a Cartesian coordinate system, and the midpoint of the South edge of cavity 1 was used to establish the origin. In order to eliminate possible bias in bidirectional measurements, we only evaluated results for South edges, and the pitch distance between South edges and the reference cavity (South edge of cavity 1).

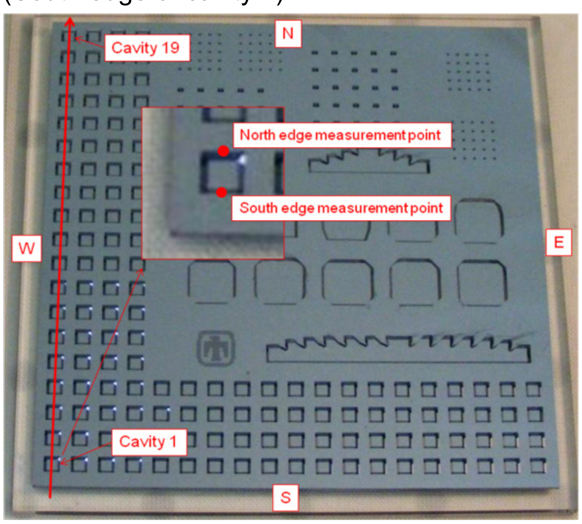

Figure 2.The reference location is at Cavity 1; measurements are made on S and N edges.

Expanded measurement uncertainties, comprising an uncertainty and coverage factor for confidence, are calculated per the ISO guide [7],[8]. Common practice is to provide coverage factor for 95% confidence (typically k=2).

Meter-scale CMM

At the time the measurements on the meter-scale CMM were made, its capability was not accredited. An evaluation of this capability estimates that for 3-D measurements, the best capability at this laboratory is ±(0.34+1.2L) µm at a 95% confidence (L in meter) [9]. Because the measurements with the meter-scale CMM were performed at 20.02°C ± 0.05°C, no temperature correction was performed on the data. Other components of measurement uncertainties are associated with the artifact itself. The determination of the edge locations are made by probing the top of the artifact, and the etched <111> sidewalls, as shown in Figure 3.

Figure 3. The top surface (<100> silicon) is evaluated as a plane from the points shown with the red dots. Sidewalls are also evaluated as planes. The edge is constructed by intersecting the <111> etched plane with the top plane.

In general, the <100> surfaces had very good reproducibility on the CMM (pooled standard deviation from each local plane of 0.034 µm). The South <111> planes have poor surface finish (combined non-flatness and roughness as large as 1.2 µm). Monte Carlo simulations of the effect of the non-flatness and roughness of the <111> walls on unidirectional measurements, including CMM capability, result in an expanded uncertainty (k=2) of 0.4 µm [6]. Based on experimental and simulation results, we use the larger of (0.34+1.2L) µm or 0.4 µm as the measurement uncertainty for South edge distances for the meter-scale CMM.

High Accuracy Optical CMM

The high accuracy optical CMM was calibrated to meet its manufacturer specifications of (0.25+L/1000) µm, L in mm, when measuring aligned with a machine major axis. Measurements were made at 22.7°C, then,

imply recommendation or endorsement by the authors, Sandia National Laboratories, Micro-Encoder Inc., or Mitutoyo America. The reported measurements are for informational purposes only.

corrected back to 20.0°C using 3.34×10^{-6}/K as the coefficient of thermal expansion (CTE) for silicon. The uncertainty in temperature measurement is assumed to be ±0.5°C (rectangular distribution), and the uncertainty in the CTE is assumed to be ±0.5ppm (rectangular). Assuming a rectangular distribution for the optical CMM specifications, we calculate a length dependent expanded uncertainty for the temperature correction of 0.82 ppm. Combining instrument and temperature correction terms, we obtain (0.29+1.4L) μm. Based on the simulation results of [6] for the uncertainty due to the artifact, we use the larger of (0.29+1.4L) μm and 0.4 μm as the measurement uncertainty for South edge distances using the optical CMM. Figure 4 shows a photograph of a typical edge as seen by the optical CMM.

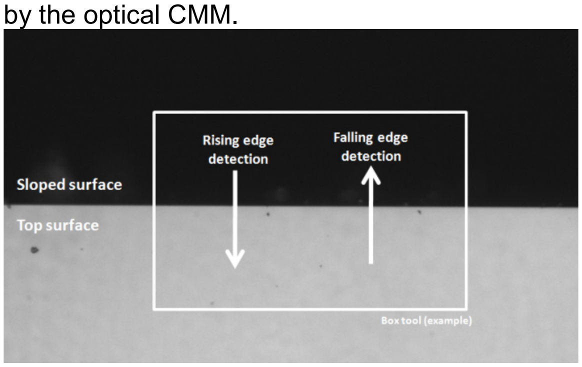

Figure 4.Two methods for edge detection.

Figure 5 compares edge detection methods on the same edge. These measurements were made on different days.

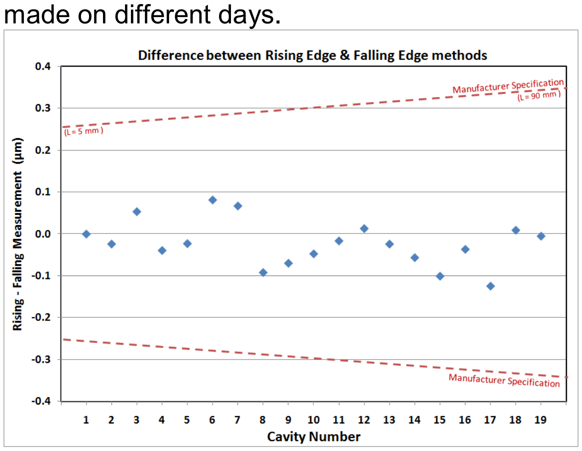

Figure 5. Comparison of edge distances when using rising edge vs falling edge detection.

Figure 6 shows the repeatability (mounting the artifact with clay on the optical CMM table) of 100 measurements. The standard deviation of the measurements is 28 nm for the edge location plotted (south edge of Cavity 1 to south edge of Cavity 19). Uni-directional and Bi-directional repeatability using other cavities were also measured and showed similar repeatability.

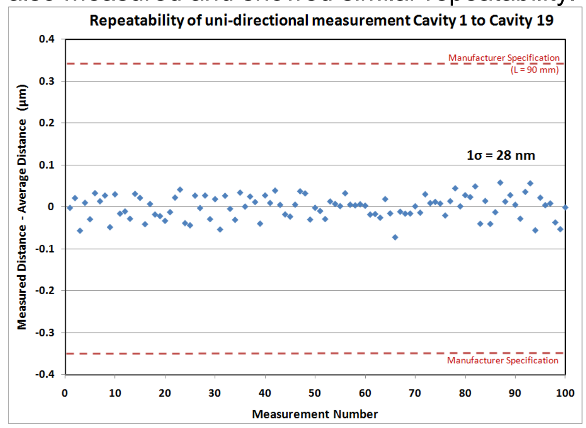

Figure 6. Repeatability of 100 measurements, using clay to fix the artifact on the optical CMM. The standard deviation was 28 nm.

Micro CMM

The Micro CMM (M-NanoCoord) has a specified MPE of (0.3+L/1000)μm, L in mm. Measurements were made at 20°C, so no temperature corrections were made. Two different M-NanoCoords were used. One was equipped with both an ultrasonic touch probe (UMAP) and an optical vision probe; the other, with a long-range ultralow force scanning probe (LNP). We similarly estimate expanded measurement uncertainty to be the larger of 0.4 μm or (0.35+1.2L) μm, with any of the three probes. A comparison of the measurements is shown in Figure 7.

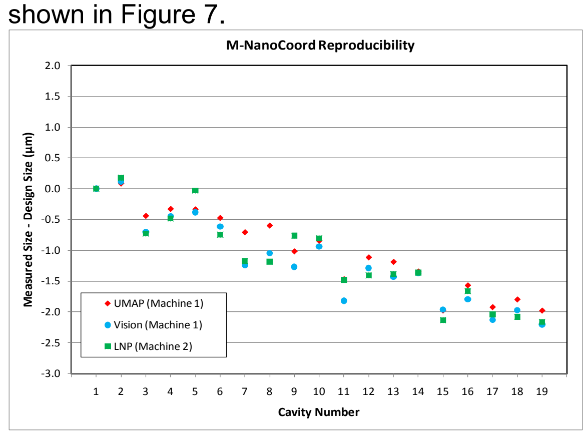

Figure 7. M-NanoCoord measurement reproducibility with three probes (UMAP, vision, and LNP) and two machines. Measurements are compared to artifact design size.

The intercomparison of 3 probing systems and two machines show excellent reproducibility, with a pooled standard deviation (3 probing systems, 18 cavities) on the order of 110 nm.

Contour Instrument

The contour instrument (Formtracer CS-3100) uses a stylus, and traces along the path with the long arrow shown in Figure 2. Figure 8 shows a typical setup for the contour instrument.

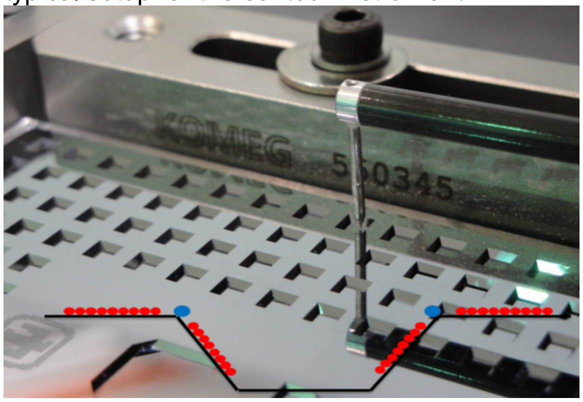

Figure 8. Setup for measurement of Formtracer. The stylus would trace points on the top and sidewalls. Intersection points were calculated, and distances calculated from the intersection points.

Repeated measurements using the Formtracer had a 0.2 μm standard deviation. This is well within the machine specification for MPE of (1+10L) μm.

Intercomparison of Measurements

We compared results from each of the four measurement instruments by plotting design size (5 mm steps) minus measured size at each measurement location. The three M-NanoCoord data measurements are averaged.

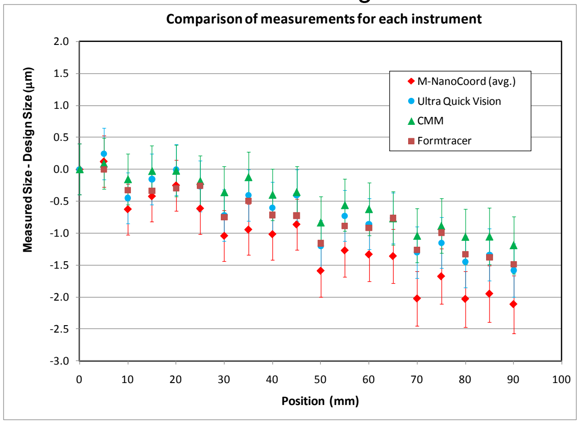

Figure 9. Comparison of measurements for each of the measurement instruments. (CMM is the meter scale CMM). Bars indicate estimated expanded measurement uncertainty (k=2). The Formtracer uncertainty is not shown, as it is significantly larger than the other instruments.

There is very good correlation between the four different instruments. All measurements agree within about 1 μm or less. When considering measurement uncertainties, the measurements overlap. This indicates that this artifact could potentially be used to calibrate optical CMMs and hybrid sensor CMMs. Since we did not give detailed instructions for setting up the measurement, we believe that much of the variation may be attributed to setup differences. It is interesting to note that the meter-scale CMM measurements trace to gage blocks calibrated at PTB, while the M-NanoCoord measurements trace to NMIJ, and the Ultra Quick Vision traces to NIST and NMIJ.

All instruments showed repeatability much better than the instrument MPE specifications.

ACKNOWLEDGMENTS

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Mitutoyo Corporation of Japan contributed the M-NanoCoord measurements.

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