ALTERNATIVE ARTIFACTS FOR EVALUATING SCANNING CMM PERFORMANCE

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1. Introduction

Coordinate measuring machines (CMMs) with continuous-contact scanning capabilities are being widely used throughout many industries. Most CMM users, if asked, say they require high density scans at high speeds with high accuracy. Obviously, there will be some point at which the accuracy of the scanned data begin to decrease with an increase in the scanning speed. Previous research [1] at UNC Charlotte has revealed that the scanning errors increased in a predictable relationship with the speed when measuring ring gages. There was also found to be a large difference between the results obtained during single point probing and scanning on the same CMM. Other research [2] at UNC Charlotte has developed a compensation model to reduce the scanning errors at high speeds, but this model is only valid for circular features. To date, our literature search has found no standard method (aside from ISO 10360-4) for comparing different CMMs based on their ability to scan at different speeds. A necessary step in comparing scanning CMMs to each other, or to discrete point CMMs, is to use a standardized test method [3]. The current ISO 10360-4 [4] standard describes circular scans on a calibrated sphere. As this sphere is of good quality, we feel that this certification test is more an exercise of the CMM motion controller than a test of the behavior of the measuring system under the excitation of measuring a real part surface. Other tests [5] have been proposed, including one that involves scanning over a gage pin with the same diameter as the probe stylus. This test produces double contacts between the stylus and the artifact where the pin is first contacted, and resulted in large errors at higher scanning speeds. Our current work examines the roles of a linear and a circular artifact, both with a sinusoidal waveform superimposed on a flat surface. By supplementing the ISO scanning tests with the measurement of these artifacts along different machine axes, and at different speeds, we can excite different frequencies in the probing system and in the machine structure. Our goal is to develop a means of distinguishing between scanning CMMs based on their accuracy at different speeds, direction of scanning. This paper describes our work in developing and measuring artifacts that will better capture how a scanning CMM will perform when measuring actual parts.

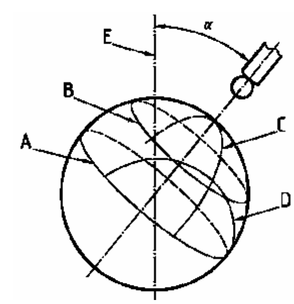

Figure 1: Target Scan Planes on the Test Sphere per ISO 10360-4

2. Current Work

To date, following three sinusoidal artifacts (See Figure 2) have been measured to compare the performance of different CMMs by varying scanning speed and direction of scan. The linear artifact was cut with a wire EDM, while the disc artifacts were turned on a diamond turning machine – the high amplitude disc using a diamond tool, and the low amplitude disc using a conventional tool.

- Linear Sinusoidal Artifact with amplitude ±2mm and wavelength 20mm.
- High Amplitude Sinusoidal Disc with amplitude ±2mm and wavelength 10mm.
- Low Amplitude Sinusoidal Disc with amplitude ±10μm and wavelength 5mm.

These artifacts have been measured on following CMMs:

- Brown & Sharpe Gage 2000 DCC using PH10T (TP20) for single point probing.
- Brown & Sharpe Global Image A using PH10M (SP600M) probe head for scanning.
- Zeiss Contura and Contour Select CMMs using VAST XT probe head for scanning.
- Leitz PMM 654 for scanning.

Figure 2: Sinusoidal Artifacts: Linear (Top), High Amplitude (Left), and Low Amplitude (Right) Artifacts

3. Scanning the Artifacts and Data Analysis

By scanning the artifact along a single axis, errors related to that axis could be isolated. The main advantage of using a disc artifact is that it could be scanned along Machine X and Y axes without moving the artifact. The scans obtained on different CMMs can be compared using two methods. One method is to fit a least square sine wave to the scanned data using MATLAB's optimization toolbox. This method gives the form error of the artifact with respect to a perfect sine wave. The deviation value, which contains both artifact and CMM errors, can be compared with data obtained from other CMMs. Other comparison method, more directly related to CMM performance, involves starting with a reference shape for the wavy surface (See Figure 3), and then comparing different scans to this reference scan. This allows us to compare different scans without fitting a least squares sine wave each time. The reference shape for the low amplitude sinusoidal disc was obtained by single point probing using Brown & Sharpe Gage 2000 DCC with a PH10T probe head and a 3×10 mm stylus. The disc was measured two times along the radius; once in forward direction and then in reverse direction. The average of the two measurements was considered as the reference. This averaging was done to reduce any noise in the data. For a more accurate reference curve, we will perform a reversal on measurements taken from a highly repeatable single point CMM, but the current reference scan is suitable for identifying differences between CMMs.

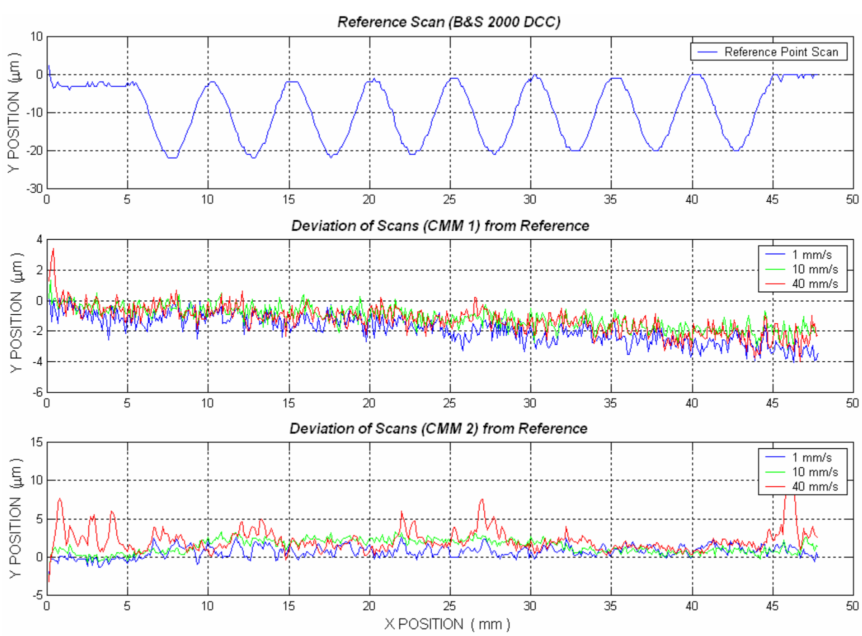

Figure 3: Comparison of scans on low amplitude sine disc scanned on two different CMMs

4. Results

While scanning the low amplitude sine disc in the xy-plane of the CMM the probe head itself does not move in Z direction. Instead, the Z coordinates are recorded by the vertical deflection of the stylus. This enables the CMM to scan at higher speeds (up to 40 mm/s) without observing much increase in the scanning error (See Figure 5 and Table 1). As the CMM is moving in a straight line for these scans, the errors observed as a result of increased speed may be associated with the probe rather than the CMM. Similar measurements on the high amplitude sine disc showed that much larger errors are observed at higher scanning speeds (See Figure 4). The reason for this increase in errors is that the CMM is no longer moving in a straight line and it has to struggle to maintain contact with the surface as it scans the artifact. Analysis of the scans on low amplitude sinusoidal disc showed that one of the CMM performed better than the other at higher scanning speeds (See Figure 5).

Table 1: Range of Deviations (µm) from Reference while scanning low amp sine disc

CMM	**Scanning Speed (mm/s)**					
	1	2	5	10	20	40
CMM 1	4.30	5.12	3.96	4.55	4.79	7.38
CMM 2	5.10	5.69	5.61	6.30	20.25	16.30

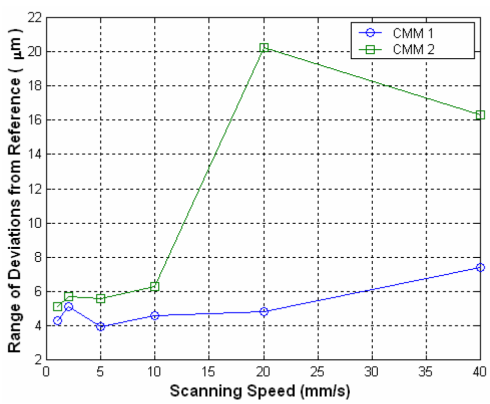

Figure 5: Performance of two CMMs while measuring low amp sine disc

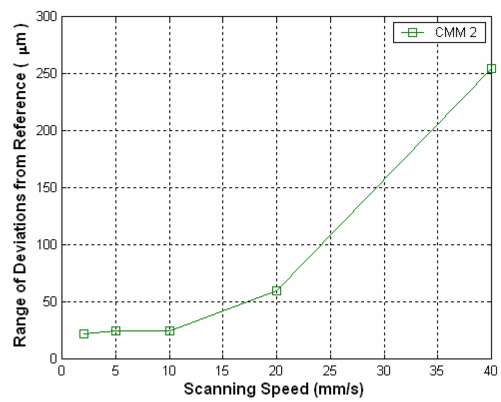

Figure 4: Effect of speed while scanning high amp sine disc

The linear artifacts have been measured in two different positions: along machine x-axis and 45° from machine x-axis. Larger errors are observed when the CMM is traveling along both the axes (See Table 2). In these scans the 1 mm/s scan was considered as a reference. All other scans were compared to the reference (See Figure 6). Other measurements have revealed that the scanning performance gets worse when the CMM is moving in all three axes.

Table 2: Range of Deviations (µm) from Reference while scanning linear artifact

Direction of scan	**Scanning Speed (mm/s)**			
	2	5	10	20
X-axis	2.96	4.78	36.93	150.63
45° from X-axis	3.02	5.03	40.65	165.40

All of the measurements reported here were taken using **closed-loop** (the path is not known *a priori*, only the starting and ending points) scanning mode. Scanning performance improves when the scanning is done in **open-loop** mode – i.e., the scan path is pre-defined.

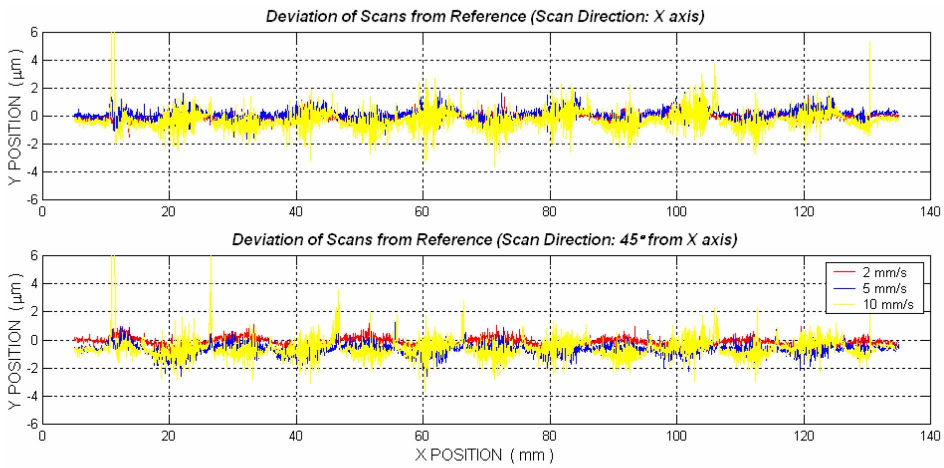

Figure 6: Comparison of scans on linear artifact scanned on CMM 3

5. Future Work

Analysis of the low amplitude sinusoidal disc reveals that there is a slope present along the wavy surface, due to out-of-squareness of our Diamond Turning Machine cross-slide. This will be corrected before the final artifact is cut. The artifacts will continue to be scanned on more CMMs to observe the performance at different speeds and in different orientations. Scanning Tests as per ISO 10360-4 will also be performed on different CMMs – varying scanning speeds will be used to study the relationship between the "official values" obtained from ISO tests and those from scanning the sinusoidal artifacts. The ultimate goal is to produce graphs similar to Figure 7, in which the difference between scanning CMMs based on their accuracy at different scanning speeds would be characterized.

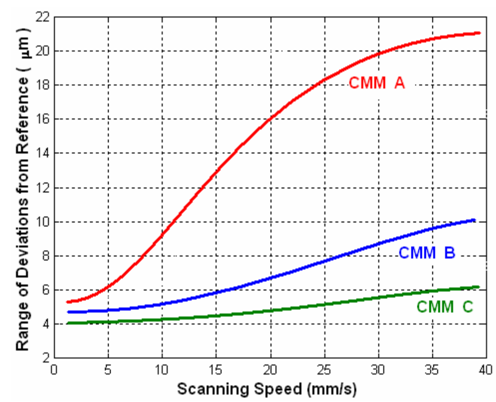

Figure 7: Desired plot comparing different CMMs

Acknowledgements

This work was supported by the industrial affiliates of the Center for Precision Metrology, a National Science Foundation Industry / University Cooperative Research Center supported under grants #EEC9811556 and #EEC0331950. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We also thank the Brown & Sharpe Manufacturing Company and J&H Machine Tools for the use of their machines and personnel for comparison testing of our artifacts.

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