ALTERNATIVE ARTIFACTS FOR EVALUATING SCANNING CMM PERFORMANCE

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1. Introduction

Coordinate measuring machines (CMMs) with continuous-contact scanning capabilities are being sold in greater and greater numbers. The following claim is representative of those touted by manufacturers: "No matter what types of feature controls you are confronted with, high data density scanning is your avenue to finding the true value". A necessary step in comparing scanning CMMs to each other, or to discrete point CMMs, is to use a standardized test method. The current ISO 10360-4 standard [1] describes circular scans on a calibrated sphere. As this sphere is of good quality, the 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. A different test has been proposed, that involves scanning over a gage pin with the same diameter as the probe stylus. This test results in a 90 degree turn in the probe path which, although more challenging than a sphere measurement, may not be representative of actual scanning. Past research [2,3,4] at UNC Charlotte has found that by scanning lobed cylindrical artifacts we may excite the resonant frequency of the probing system, resulting in severe performance degradation as the feature is scanned. Our current work examines the role of linear artifacts with a periodic (sinusoidal) waveform superimposed on a flat surface. By measuring 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 ability to measure different spatial frequencies and amplitudes at different speeds. This paper describes our work in developing and measuring artifacts that will better capture how a scanning CMM will perform when measuring actual parts.

2. Current Work

To date, the linear sinusoidal artifact (Fig. 1) has been measured to study the performance of the CMM by varying different parameters, such as:

- Scanning speed
- Data density
- Direction of the scan
- Position and orientation of the artifact within the machine volume
- Stylus diameter and probe type

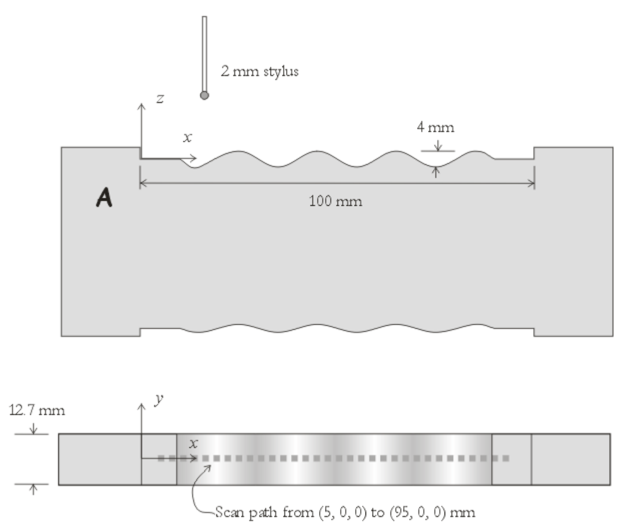

Fig. 1. Sinusoidal Artifact

3. Scanning the Sine Artifact

The part coordinate system is constructed by defining the datum planes as follows:

- The Primary Datum (z) is constructed from the flats at each end of wavy section.
- The Secondary Datum (y) is constructed along midplane of the artifact.
- The Tertiary Datum (x) is established at end of the "cutout."

The sine artifact is mounted on the CMM in three different positions. In the first position, the part coordinate system is parallel to the machine coordinate system; in the second position, the part (with its coordinate system) is rotated 45° about machine z-axis; in the third position, the part is rotated 45° about Machine z-axis and inclined at an angle of about 45° from the horizontal (machine xy-plane). In every case, the probe stylus was oriented "straight down" in the minus-z direction.

The artifact is scanned along the path shown in Fig. 1. This scan path is from (5, 0, 0) to (95, 0, 0) mm in the part coordinate system. The wavy (sinusoidal) portion of this path is from $x = 10$ mm to $x = 90$ mm.

4. Data Analysis

In order to remove errors in the measurement of the Primary Datum surface, we first refit the z=0 line to the initial and final segments of the scan. Typical values for the slope of this line are between 0 and 8 μm/m, and are thus virtually negligible (a slope of 8 μm/m corresponds to an angle of 0.00046°). The measurement data are rotated through this angle. A least square sine wave is then fitted to the wavy portion of the data. MATLAB's optimization toolbox is used to fit these data to the following equation:

$$LS\ Sine\ Wave = A - B \sin\left(2\pi C \frac{x - D}{E - D}\right)$$

where

A	=	Baseline (Vertical Offset)
B	=	Amplitude
C	=	No. of waves
D	=	x Start Point
E	=	x End Point

The least squares (LS) fit of the sine wave may not have a zero mean line; therefore parameter A controls the vertical position of the LS sine wave. Parameter B controls the amplitude of the LS sine wave, which is nominally 2mm. Parameter C is the number of waves in the artifact; ideally 4 waves. Parameters D and E control the horizontal position of the LS sine wave.

Deviations from the least square sine wave were determined by using:

$$Deviations = Rotated\ Data - LS\ Sine\ Wave$$

Form error of the artifact was determined by:

$$Form\ Error = Maximum\ Deviation - Minimum\ Deviation$$

5. Results

The artifact was scanned using six different scanning speeds: 1, 2, 5, 8, 10 and 20 mm/sec. Data density was set at 10 points/mm. Results in Table 1 and Table 2 corresponds to scans taken parallel to the machine x-axis. It could be observed from Table 1, that the form error is in the range of 14.7 to 15.7μm. From this data, we see that change in scanning speed did not result in a significant change in the form error.

Table 1. Effect of different scanning speeds on the form error (FE)

SCANNING SPEED	DATA POINTS	LEAST SQUARE SINE WAVE PARAMETERS					DEVIATION FROM LS SINE WAVE		
		A	B	C	D	E	MAX	MIN	FE
mm/sec	points	μm	mm	waves	mm	mm	μm	μm	μm
1	971	-0.9	1.9982	3.9865	10.0013	89.7293	8.4	-6.7	15.2
2	974	-0.7	1.9982	3.9875	10.0025	89.7493	8.3	-6.5	14.7
5	974	-1.0	1.9982	3.9991	10.0026	89.9822	8.6	-6.9	15.5
8	974	-1.1	1.9983	3.9871	10.0026	89.7427	8.8	-7.0	15.7
10	964	-1.7	1.9983	3.9963	10.0019	89.9266	9.0	-6.7	15.6
20	918	-2.3	1.9983	3.9885	10.0018	89.7697	8.0	-6.9	14.9
Nominal Values		0	2	4	10	90			

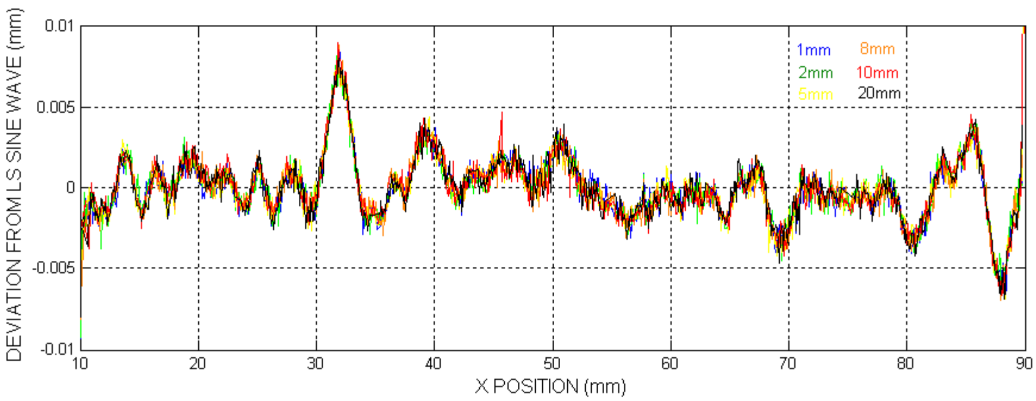

Fig. 2. Deviations from LS sine wave for different scanning speeds

To study the repeatability of the parameter-fitting methods, five scans were repeated with a scanning speed of 2 mm/sec. From Table 2, the average form error (with respect to a fitted sine wave) is 15.4µm with a standard deviation of 0.6µm. Ten repeated scans of the artifact on a second CMM at UNCC resulted in an average form error of 14.3µm with a standard deviation of 0.6µm.

Table 2. Results from five repeated scans

SCANNING SPEED	SCAN NO.	DEVIATION FROM LS SINE WAVE		
		MAX	MIN	DIFF
		µm	µm	µm
2 mm/sec	1	9.0	-6.1	15.1
	2	9.4	-6.9	16.4
	3	8.8	-6.9	15.7
	4	9.1	-6.1	15.2
	5	8.3	-6.5	14.8
		Average		**15.4**
		St. Dev.		**0.6**

A second comparison method, more directly related to CMM performance, involves starting with a reference shape for the wavy surface, and then comparing different scans to this reference scan. This allows us to see the effect of different scanning speeds and probe setups without fitting a least squares sine wave each time. Fig. 3 shows a comparison of scans with 2, 5, 8 and 10 mm/sec scanning speeds (scan direction: X). Fig. 4 shows the comparison of a 20 mm/sec scan in X direction with the reference scan. In each of these figures, the reference scan is an average of ten scans obtained on UNCC's Leitz PMM with 1 mm/sec scanning speed in X-direction.

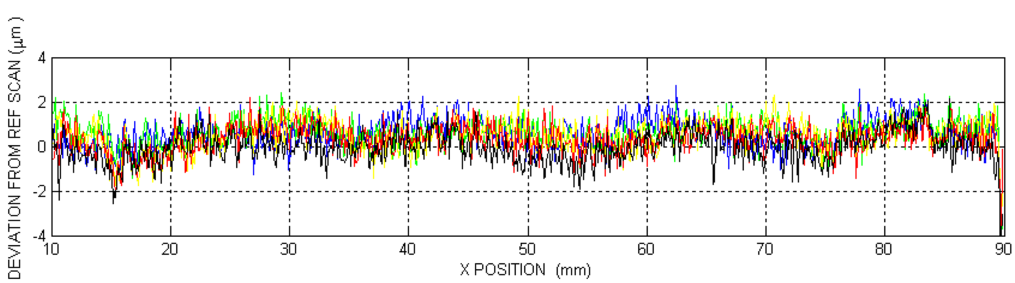

Fig. 3. Scans with 2, 5, 8, 10 mm/sec scanning speed compared to the reference scan

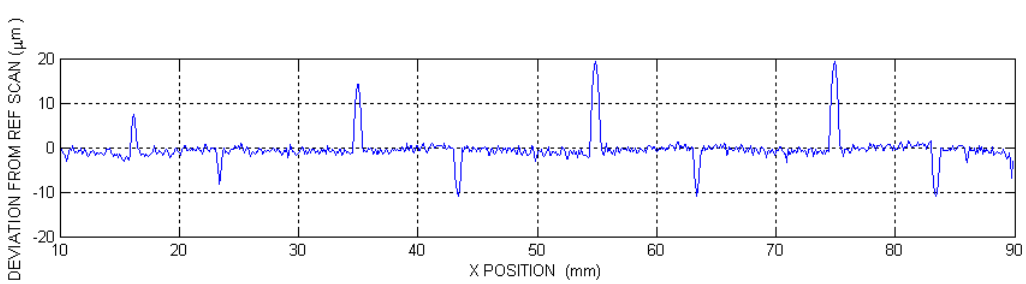

Fig. 4. Comparison of a 20 mm/sec scan in X direction with the reference scan

Fig. 5 shows the comparison of scans in XY and XYZ direction, both with a scanning speed of 1 mm/sec. Fig. 6 shows the deviations from least square sine wave for 2 mm/sec scan in XYZ direction. By comparing Fig. 2 and Fig. 6, we observe that when scanning in XYZ direction, a small increase in the scanning speed may result in a significant change in the deviations.

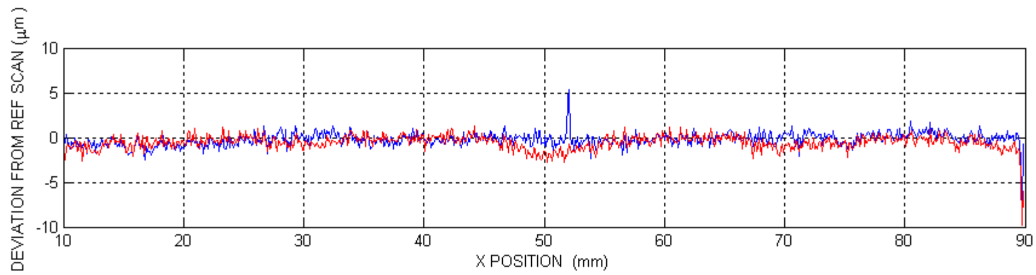

Fig. 5. Scans in XY and XYZ direction compared to the reference scan in X direction (scanning speed: 1 mm/sec)

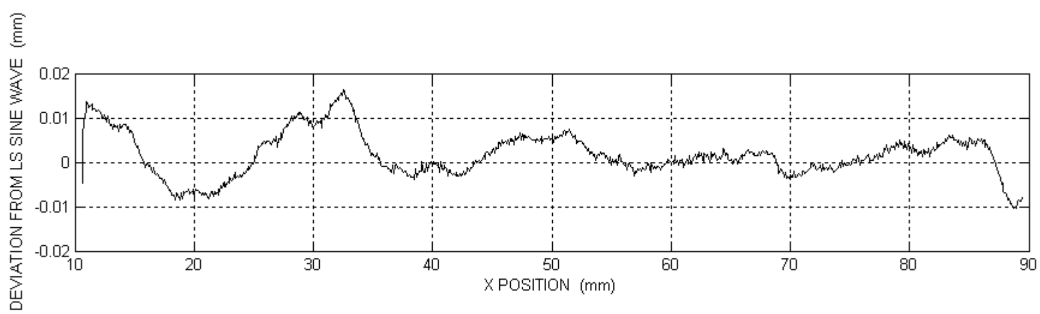

Fig. 6. Deviations from LS sine wave for 2 mm/sec scan in XYZ direction

6. Future Work

The data analysis is currently done without using any kind of external filters. Using a suitable high frequency filter may reduce the noise in the data. This would enable us to compare the data taken on different CMMs. In order for this comparison, we would consider one of the scans as a reference scan. All the other scans will be compared to the reference scan. Another sinusoidal artifact is being considered instead of the linear sinusoidal artifact (Fig. 7). This artifact would have a better surface finish.

Fig. 7. Another sinusoidal artifact

Acknowledgements

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References

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