

Artifact selection and its role in CMM evaluation

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Abstract

The standard method of Coordinate Measuring Machine evaluation is to measure an artifact or series of artifacts to establish either the distribution of reported values, or the relationship between the reported value and some "known" value for a measurand. International standards for CMM accuracy testing require the use of a calibrated artifact to establish traceability to the international unit of length. The U.S. national standard, B89.4.1M, permits the use of a ballbar of uncalibrated length to determine the volumetric performance of the CMM. Finally, Gage R&R studies, as described in the [Measurement Systems Analysis] book, use customer-supplied parts that (preferably) exhibit variations over the entire tolerance band.

In this paper we compare how we may use the data that are obtained from these three methods, which use very different artifacts. The value of these data for CMM evaluation is discussed in terms of the intended use for the CMM; it may be used as a final inspection gage in a laboratory, as an audit gage on the shop floor, or as a process control device in or near the manufacturing process.

Introduction

A CMM is located next to a manufacturing line, and is used for first part inspection and periodic sample measurements for control of the machining operations. In the metrology laboratory, a different CMM is used to measure setting rings used for the factory's hand gages. And, in the design laboratory, a scanning CMM measures prototype cam profiles for reverse engineering using the company CAD system. Each of these CMM's has a sticker indicating that it has been certified to the manufacturers specifications, but does this mean that each measuring machine is doing its job well? The answer to this question lies in the relationship between the artifacts used to certify the CMM and the measuring task for that machine. The selection of the artifact for certification is determined by the appropriate standards and is, for the most part, beyond our control. The portion of this problem that we can control is the procedure we use for supplemental and interim testing of the measuring machine.

Let's consider each of the machines in our example. The CMM in the metrology lab is being used to measure simple geometries on parts that have good surface finish and, probably, low form error. The CMM on the manufacturing floor is measuring parts with complex geometry, possible contamination, and varying thermal state. The CMM in the design lab is in a fairly clean

environment, but is required to measure a wide variety of geometries varying surface characteristics – e.g. some layered manufacturing processes used in rapid prototyping leave distinctive surface "ripples" on nominally flat surfaces.

Metrology Lab:

The main application of this CMM is in checking various setting masters, and acting as an audit check for parts measured on the shop floor. The basic length and diameter measurements taken on gage blocks and rings are similar to the measurements used in the certification of the measuring machine. Because of the similarity of the measurement application and the certification procedure, the certification gives an excellent indication of how the CMM will perform when making these gage measurements.

Shop Floor:

The application of this machine is first part inspection, and process control. It is here that the differences between the certification process and the application are greatest. We may have a volumetric performance of 0.008mm, but how does this relate to the position reported for a bore, which is located in a Datum Reference Frame based on casting locators? To address this we must consider both the ability of the CMM to measure individual points in a repeatable manner, and the accuracy/uncertainty of the specific measurand. At times, the datum placement and the measured feature may allow us to approach the stated uncertainty of the CMM, but other measuring tasks may be less stable. In addition, we must consider the role of within-part variation as it affects the measuring results, and how these data are fed back into the manufacturing process.

Scanning CMM:

This CMM is used to measure both known and unknown profiles, either for conformance assessment or reverse engineering. While the accuracy requirements for conformance assessment are widely known – at least from a heuristic standpoint (e.g. the 10:1 rule) – the requirements for reverse engineering applications are not well understood. Often, it is a small area of a part that is being captured, and the relative location of points within that area may be more important than the relationship to those points to the rest of the part. The use of data filtering and algorithm selection is important for handling these dense data available from scanning, and the influence of these on the measurand may depend on the scanning parameters. This issue is largely avoided in dimensional inspection standards, although ISO 10360-4 notes: "algorithms and parameters used should be the same as for normal workpiece measurement ..."

So, as we go from the metrology lab to the shop floor to scanning, we depart more and more from the certification in terms of the type of measurements taken. Because the standards are fixed as far as the type of artifact used and the evaluation of the data, it is up to the user to supplement the certification tests with artifacts and procedures that better represent the end use of the CMM. To insure suitable machine performance between certifications, these should be incorporated in an interim testing plan.

Interim Tests

What's the worst nightmare for a measuring facility? You've been happily measuring away, and the equipment and software seem to be performing nicely, and then at the annual re-certification you find that there is a large systematic error in the measuring system that affects all of your measurements. Worse, you don't know when this error was introduced. To reduce, and hopefully all but remove the possibility of this occurrence, we use interim testing to catch common problems in the measuring system. This is our opportunity to tie measurements on an artifact to those in our application. In order to establish a set of baseline measurements, it is advisable to perform this test immediately following the calibration and certification of the CMM.

From ISO 10360-2, we find a nice description of a possible artifact (in addition to the usual ball-plate, ball-bar, etc.): *"a purpose-made test piece which has features representing typical geometrical elements, is dimensionally stable, mechanically robust, and which has a surface finish that does not significantly affect the uncertainty of the measurement."*

The interim test should exercise the CMM throughout its full operating range, and measure the types of features used in the application. The test should also include measurements that are sensitive to frequent causes of machine error (squareness, probe performance). For example, although good measurement practice may not recommend a length measurement based on only two individual points, this is a useful way to check for machine repeatability or hysteresis which might be masked by the repeated measurements on each side of a feature.

GR&R studies

Because it can be very difficult to infer the variability that will be present in part measurements from the a machine certification, or even from statistics of certification-type measurements, the GR&R study can be invaluable for the assessment of CMMs in an industrial setting. These studies allow us to use a series of different parts that are "representative" of our process, to assess the ability of the measuring system to obtain the same measurand value for repeated measurements of the same parts. From the GR&R test we can infer the variability that we might associate with the measurement of an individual part, as well as some components of the uncertainty for that measurand.

The main enemy of GR&R studies, and of using "real" parts for interim testing, is the presence of within-part variation. This is where several different measured values can be determined for a single measurand using the defined measurement technique (e.g. consider the two point diameter measurement of a part with an oval cross-section). While a GR&R study will not catch all sources of measuring system variation, it is nonetheless a valuable tool in determining the appropriateness of a CMM and its environment for a particular task. As the GR&R does not provide any information about bias in the measurements, it is often useful to have a "golden" part with good geometric characteristics (minimal within-part variation) and "known" values for the measurands. If this part is used in conjunction with the GR&R study, we can not only see the difference (if any) in the variability between the average part and the golden part, but check for bias in the measurements.

Alternative artifacts

It may be useful to consider an artifact that is somewhere between the calibrated gage block, ring, etc., and the part from the shop floor. This is reflected in the ISO's "purpose-made test piece." The benefit of a calibrated artifact is the direct identification of machine errors in addition to repeatability. The benefit of a more general artifact is that it provides alternative ways to compare measuring machines.

One area where additional artifacts may be particularly useful is in attempting to classify scanning CMMs. The current ISO 10360-4 standard 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 surface¹. 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° turn in the probe path which, although challenging, may not be representative of actual scanning.

At UNC Charlotte, we have performing tests using the gage pin artifact [Freire] - see Figure 1a, and also numerous scans of bores with periodic errors (lobes). We have found that by scanning the lobed artifacts we may excite the resonant frequency of the probing system, resulting in severe performance degradation as the feature is scanned [Muraldihar]. We are currently examining the role of linear artifacts with a periodic error superimposed on a flat surface - see Figure 1b. 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. To address the calibration of these artifacts, we will examine reversal techniques and discrete point measurement, and also compare to scans taken with our Talysurf machine.

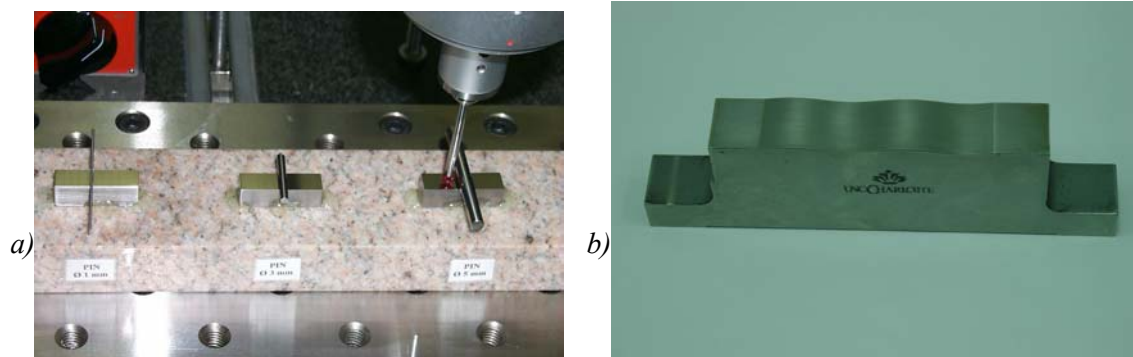


Figure 1: a) Pin tests in progress, and b) linear scanning artifact.

Conclusions

In all but the most basic measuring applications, the measurement of supplemental artifacts will increase our knowledge about the state of the measuring system. The incorporation of these artifacts in a well structured interim testing program will minimize the probability that our CMM will cease to meet the certification requirements without our knowledge. The use of alternative

¹ Thanks to Steve Phillips for pointing out this distinction between the two problems.

artifacts for scanning CMMs raises additional issues, and further work is needed to develop artifacts that can be used in the certification of scanning CMMs and used to represent "typical" measuring situations for these measuring machines.

References

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