CMMs and PROFICIENCY TESTING

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Abstract

Many factors add to the variation in CMM measurements. Some originate in the machine itself or the environment. Some come into play in every measurement and some depend on the probe configuration used, including probe articulations or changes. Others depend on the part being measured; its rigidity and thermal properties and still others depend on the measurement strategy and point distribution chosen by the operator. Since geometrical requirements, whether specified using ANSI/ASME Y14.5 or ISO 1101 apply to a continuous surface, it is impossible to measure GD&T "in accordance with the standard" on a CMM. Therefore CMM measurements of geometry become a question of what constitutes an acceptable approximation. For these reasons and because there is a lack of formalized ways of estimating the uncertainty of CMM measurements, proficiency testing can be a valuable reality check for how well one can measure with a CMM.

Introduction

This paper discusses the considerations that went into the development of HN Proficiency Testing's CMM proficiency test. The intent is to illustrate the process of developing a proficiency test for a defined purpose, particularly in the CMM field.

Proficiency Testing

Proficiency testing is a set of methods for evaluating the measurement results of laboratories, by comparing them to reference values, the results of other laboratories, or both. Of particular interest in the case of calibration or dimensional inspection laboratories is the question of whether the laboratory can measure as well as its claimed uncertainty implies.

This particular type of proficiency testing is often referred to as interlaboratory comparison. There are several ways to evaluate the results of proficiency tests, but for this type of tests, the normalized error or E_n-value is the most meaningful metric. The formula is as follows:

$$E_n = \frac{V_{Lab} - V_{Ref}}{\sqrt{U_{Lab}^2 + U_{Ref}^2}}$$

where:

V_{Lab} is the laboratory's measured value
V_{Ref} is the reference value
U_{Lab} is the laboratory's expanded uncertainty (using k=2 or approximately 95% coverage)
U_{Ref} is the expanded uncertainty of the reference value (using k=2 or approximately 95% coverage)

An E_n-value in the interval -1 to +1 indicates that the laboratory agrees with the reference value within the stated uncertainties of the two values. An E_n-value outside this interval indicates that the disagreement between the laboratory and the reference value is larger that what can be explained by the claimed uncertainties.

The reference value and reference uncertainty can be obtained in different ways. Typically, it is either obtained from a laboratory in which the test administrator has high confidence, or from an average of the participating laboratories, if no suitable reference laboratory can be found.

In a proficiency testing round the artifact(s) are sent from one participant to the next, while the measured values are to be kept confidential. A major role of the administrator is to keep these values confidential and to ensure that each participant can only identify his/her own results in the final report. This is usually accomplished by using a code for each participant in the report.

Typical graphical representations of proficiency test results are given in figures 1 and 2.

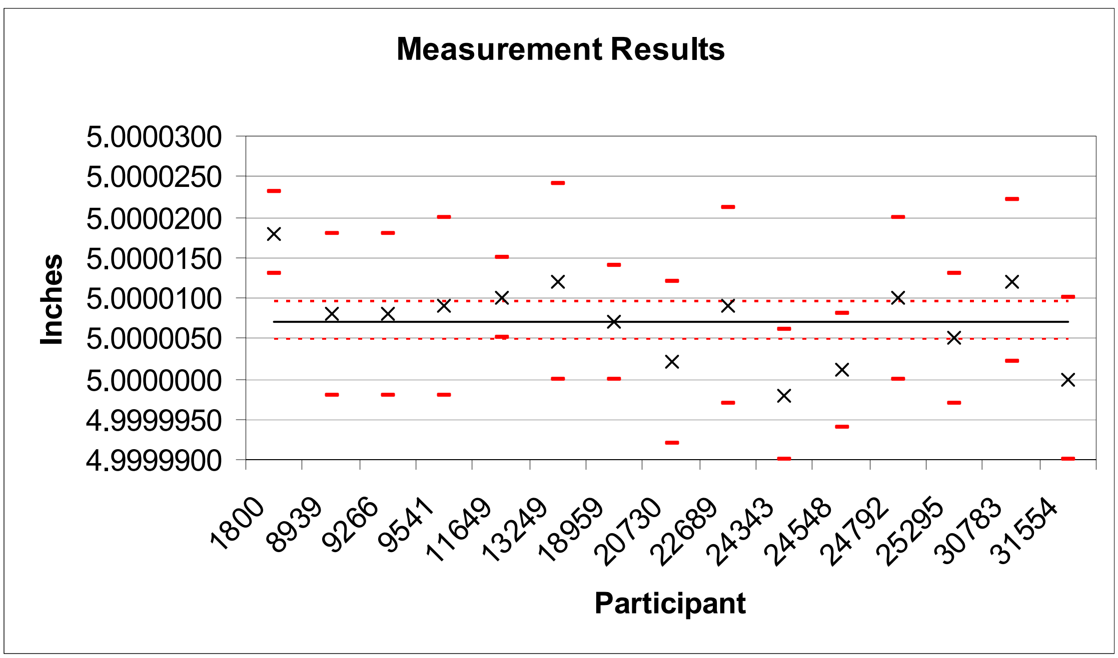

Figure 1: Plot of measured values and uncertainties (simulated results).

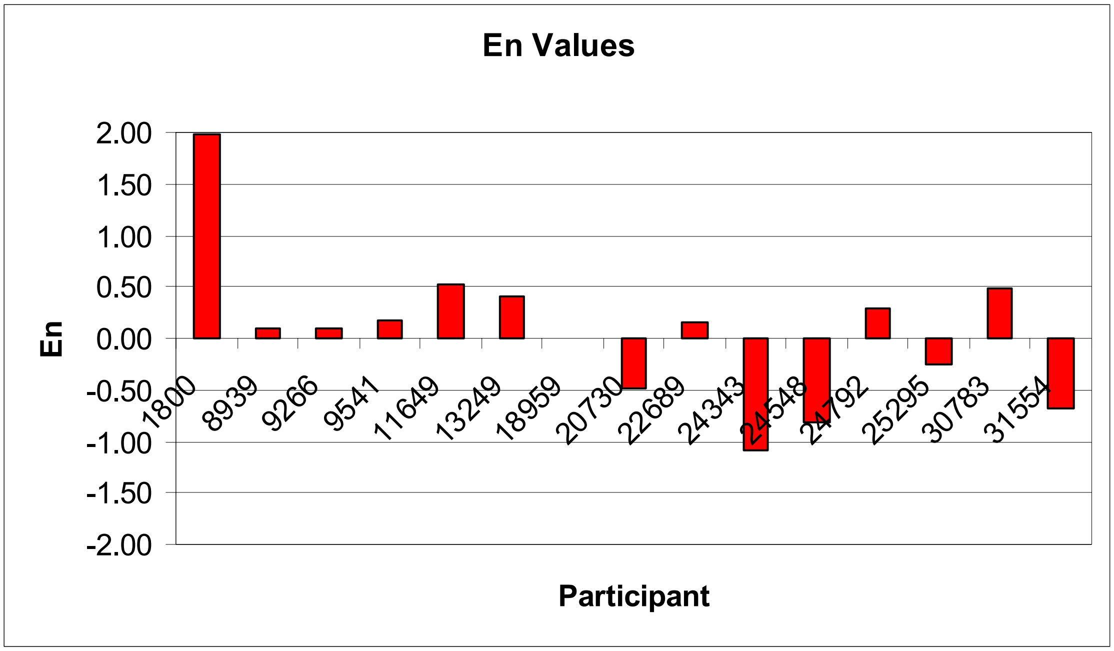

Figure 2: E_n plot (simulated results).

Considerations for a CMM Proficiency Test

A properly designed proficiency test can be very accurate in pinpointing where a laboratory may have problems, whereas a poorly designed test only gives an overall "go"/"no go" answer with little or no information that can help a laboratory diagnose any problems it may have.

Given the complexities of CMM measurements, it is important to design the test such that it is easy for the participants to see where problems occur and what the likely cause of the problem is.

Consequently, the first step in designing the test is to identify the most likely potential problem areas.

For the CMM measurement test the areas considered are:

- The accuracy of the CMM itself
- The influence of the environment
- The influence of the probe configuration
- The influence of a probe articulation or changing mechanism
- The influence of the measurement strategy and point distribution

The challenge is to design a test that allows the administrator and the participant to identify which of these, if any, causes problems or is not accounted for properly in the laboratory's uncertainty budget.

Choice of Artifact

The choice of artifact is the first design decision. As temperature effects and geometry effects, such as squareness, are length dependent, a relatively large artifact will enable the participants to better see the influence of these effects. On the other hand, a large artifact is difficult to transport.

An artifact made of aluminum (or plastic) will be more sensitive to temperature variations than one made of steel or cast iron. It will also be lighter and therefore easier to transport. However, to challenge the best measuring capability for most laboratories, the artifact must be made of an iron-based material. Further, it requires relatively finely machined surfaces to accomplish the best measuring capability and finally there is a concern over the stability and durability of the artifact.

A cast iron engine block was chosen for the artifact, see figure 3. The main reason for choosing the engine block is that it is a relatively high-precision off-the-shelf artifact. This is the only way to get an accurately machined artifact, which is not cost prohibitive.

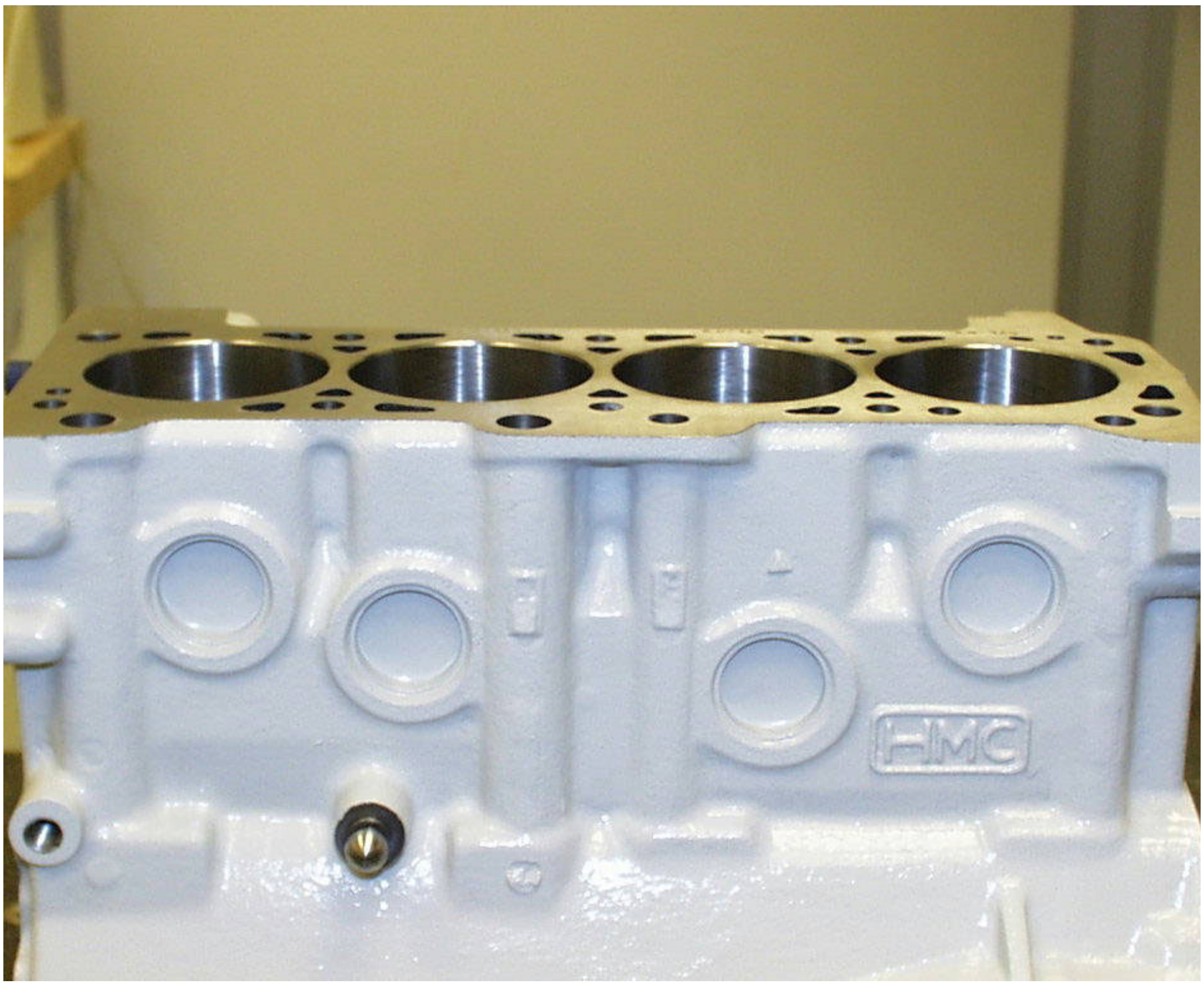

Figure 3: The engine block used for the CMM proficiency test.

Being iron based, the thermal expansion coefficient of the artifact should allow most laboratories to measure up to their best capability, but with a length of about 300 mm the block is large enough to show errors, if the temperature effects are not appropriately taken into account. Further, being fairly solid, it is reasonable to expect that the artifact will be sufficiently stable over time. While the weight of 70 lbs is a concern, it is still feasible to ship the artifact between participants.

Defining the Tests

Having chosen the artifact and thus the amount of temperature influence on the measurements, the next step is to define the test measurements, such that the maximum amount of information can be extracted from the results. To accomplish this, it was decided to split the test up into 3 parts:

Part 1:	All probing locations are defined. All probing locations can be reached with a straight-down probe.
Part 2:	All probing locations are defined. A probe cluster, an articulating probe or a probe changer is required to reach all probing locations.
Part 3:	Only the features to be probed are defined. A probe cluster, an articulating probe or a probe changer is required to reach all features.

It is fairly easy to identify, where a laboratory may start having trouble with its measurements when the test is split up this way.

Information from test 1

Test 1 is a best-case scenario. Since all the probing locations are defined, the measurement strategy is as far as possible taken out of the hands of the operator and since all the probing locations can be reached with a straight-down probe, there is no probe changing problems or problems with gravity.

If a laboratory has trouble with these measurements, then the indication is that the laboratory either has failed to take the basic uncertainties of the machine and the environment into account, or that there is something extraordinary wrong with the machine (or the software). An analysis of the laboratory's stated uncertainty compared to successful participants can help determine which case it is.

Information from test 2

Test 2 adds the complication of a probe cluster/articulation/changer over test 1.

If a laboratory successfully passes test 1 but fails test 2, then the indication is that the laboratory has failed to take the added uncertainty of the probe cluster/articulation/changer into account.

Information from test 3

Test 3 adds the complication of letting the operator choose the number of points and location of points over test 2.

In many cases this is the largest uncertainty contributor in CMM measurements, as variations in probing strategy can have very significant influence on the measured results. However, this is also the most realistic test, as a part print usually does not indicate specific points, but only the features to be measured, so this is the type of measurements a laboratory will most likely be making on a daily basis.

As geometrical requirements, whether specified using ANSI/ASME Y14.5 or ISO 1101 apply to a continuous surface, it is impossible to measure "in accordance with the standard" on a CMM. Therefore a laboratory has to take into account what the limited sampling adds to the uncertainty. This is a very stealthy uncertainty contributor, as it only manifests itself when results obtained using different strategies are compared and most laboratories are unlikely to vary their measurement strategy to evaluate this contributor.

If a laboratory passes tests 1 and 2, but fails test 3, then the indication is that the laboratory has failed to take the uncertainty of the measurement strategy into account.

Conclusion

This paper has discussed the considerations for the design of a CMM measurement proficiency test and how the ability to diagnose where problems occur depends heavily on the design of the test.

The paper used as an example a particular test offered by HN Proficiency Testing, which is primarily aimed at laboratories, which measure geometrical tolerances on machined parts. A test aimed at e.g. laboratories measuring pointsets on sheetmetal or molded plastic parts and compare them to nominal points defined in a CAD file, would have to be defined differently in order to diagnose the particular problems in these types of measurements.