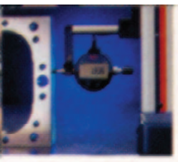


CONFORMANCE, TRACEABILITY, AND THE RISING ROLE OF MEASUREMENT UNCERTAINTY

CUSTOMER-SUPPLIER DISAGREEMENTS OVER PRODUCT COMPLIANCE TO SPECIFICATIONS CAN BE COSTLY TO ALL PARTIES INVOLVED. RECOGNIZING OF THE IMPORTANCE OF MEASUREMENT UNCERTAINTY WHEN DETERMINING CONFORMANCE TO DIMENSIONAL SPECIFICATIONS HAS RISEN SHARPLY IN RECENT YEARS.

Courtesy of Sterling Multi Products

K. D. Summerhays, MetroSage LLC

Specification of part geometry through geometric dimensioning and tolerancing (GD&T) is often misinterpreted. While standards such as ASME Y14.5M-1994 codify the practice, "knowledgeable" practitioners will still disagree on the meaning of the callouts on a given part. These differing opinions can complicate the definition of conformance.

ENSURING VALID SPECIFICATIONS

The customer ordinarily undertakes the analysis resulting in the GD&T specifications of the part to be produced by the supplier. When a supplier agrees to produce the part according to these customer specifications, the first hazard is that the GD&T specification is in some way incomplete, inconsistent, and/or ambiguous.

Careful study of the specifications is vital to avoiding later disputes. Mistakes can usually be corrected inexpensively at this stage. If necessary, third party experts can resolve disagreements, but automation of this process is now possible. Tolerance checking software, using encoded GD&T expertise, can quickly flag part feature characteristics (size, location, orientation, form) that aren't fully controlled or that are overcontrolled.

The burden of good design practice remains with the customer because the software cannot judge for part functionality or design intent – but it does efficiently address the clarity of the specification.

CMM: WEAPON OF CHOICE FOR GD&T

GD&T requirements typically assess complex 3-D interrelationships of part feature characteristics. The coordinate measuring machine (CMM) is arguably the best tool to meet this challenge for parts of moderate size.

Powerful data-analysis software transforms raw sample points taken on part feature surfaces into reportable GD&T parameters, such as the parallelism of the cylinders in an engine block. The CMM's versatility makes it especially economical for small manufacturers, so this discussion will be on CMM-based measurements from this point forward.

The question is this: How much confidence can be placed in the values reported by a CMM?

WHY IS MEASUREMENT UNCERTAINTY AN ISSUE?

The Reference on Constants, Units and Uncertainty promulgated by the National Institute of Standards and Technology (NIST) makes the importance of measurement uncertainty assessment clear: "A measurement result is complete only when accompanied by a quantitative statement of its uncertainty."

The uncertainty is ordinarily expressed as a range of values within which, at a specified level of confidence, the true value of the quantity measured is believed to lie. Applying this to CMM-based measurements, what is required is a task-specific uncertainty estimate for each and every GD&T parameter.

It is necessary to make statements like, "The uncertainty of the diameter of this particular 75.00-mm diameter hole (produced under specific manufacturing conditions) is ± 0.05-mm at 95 percent confidence (when determined with this particular measurement system, using this particular measuring protocol, under this particular set of environmental conditions).

The parenthetic phrases here suggest many factors contribute to task-specific measurement uncertainties. The same power and versatility that make the CMM attractive for measuring also make assessing these measurement uncertainties a formidable task. Before addressing that issue, consider two important roles that measurement uncertainty plays in CMM applications.

The first is with respect to measurement traceability; the second is in regard to conformance decisions.

TRACABILITY OF CMM MEASUREMENTS

The ISO International Vocabulary of Basic and General Terms in Metrology defines traceability as "the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties."

The end of this definition emphasizes the prominence of uncertainty evaluations in completing the traceability chain. Simply having a CMM calibrated doesn't make its measurement results traceable. If CMM-derived GD&T measurements are to be traceable, include defensible task-specific uncertainty evaluations as part of the measurement report.

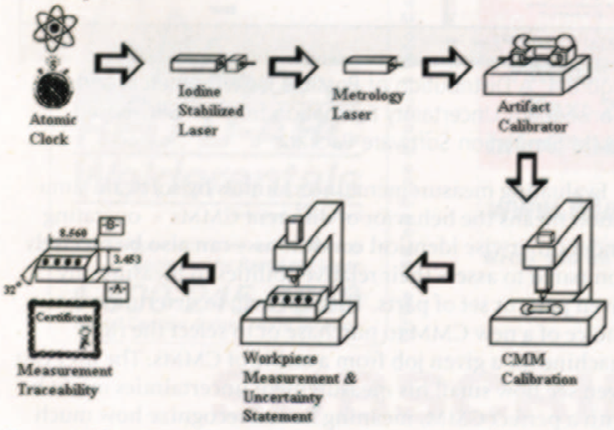
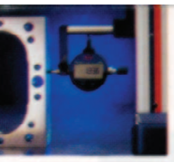


Figure 1. The CMM Traceability Chain

CONFORMANCE DECISION RULES

The economic importance of uncertainty evaluation is emphasized in recent standards ISO 14253-1 and ASME B89.7.3.1. These guide the formulation of decision rules to govern the acceptance or rejection of articles of commerce.

Figure 2 shows that if a decision rule imposed by a customer requires the specification zone to be reduced by the measurement uncertainty to determine the zone of acceptable values, there is a clear economic penalty for greater uncertainty.



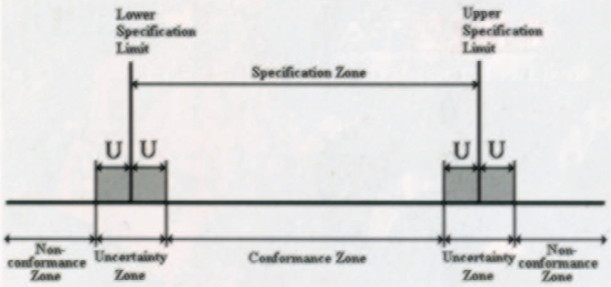


Figure 2. The Role of Measurement Uncertainty in Product Conformance/Non-Conformance.

This example shows that if a decision rule imposed by a customer requires the specification zone be reduced by the measurement uncertainty to determine the zone of acceptable values, there is a clear economic penalty for greater uncertainty. A higher cost to produce an acceptable item is likely.

EVALUATING TASK-SPECIFIC MEASUREMENT UNCERTAINTIES FOR CMMS

Many "influence quantities" contribute to the uncertainty in a CMM-based measurement of a GD&T parameter. Figure 3 illustrates their general categories.

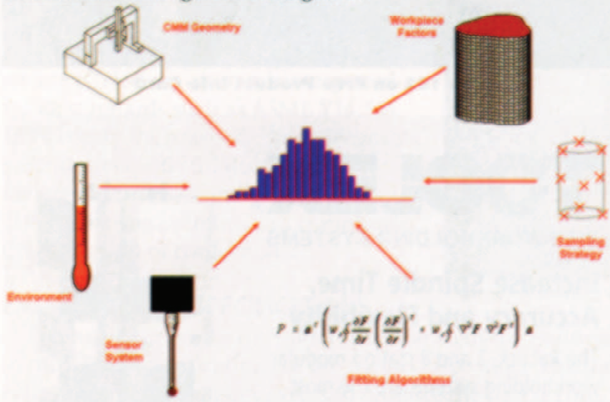


Figure 3. General Categories of CMM Measurement Influence Quantities

The number of these influences, and the complexity of their interactions, make the application of traditional "error budget" approaches to measurement uncertainty estimation largely impractical for CMMs. The ISO 15530 series offers five alternative approaches. When considering the versatility, economy of use, robustness and comprehensive character of each approach, Computer Simulation is the winner.

Computer Simulation repeatedly simulates the actual measurement of the part under various conditions. The ranges of variability of influence quantities such as CMM geometry errors, sensor errors, environmental conditions, etc. are employed in a mathematical model allowing their influences to be reflected in the resulting ranges of GD&T parameters – precisely consonant with the concept of measurement uncertainty.

In developing Computer Simulation, NIST researchers Dr. Steven Phillips and his coworkers conceived the statistical method known as "Simulation by Constraints" (SBC), which recognizes that the CMM user often has incomplete and undetailed information about errors, for example, in his CMM. He may actually have only an indication from the CMM manufacturer about maximum permissible errors for a given model of machine.

CMM performance data specified by ASME B89.4.1 serves as input to SBC-based software, along with other information about the measurement system (e.g. sensor performance test data), environment (e.g. thermal conditions of the machine and part) and measurement protocol (e.g. surface sampling strategy) for the part.

These data generate uncertainty estimates for the desired GD&T parameters. SBC technology has been commercially implemented to give the CMM user ready access to assessing the uncertainty of his final reported measurement data. An example of one GD&T parameter's range of measurement results and corresponding measurement uncertainty at 95 percent confidence is shown in Figure 4.

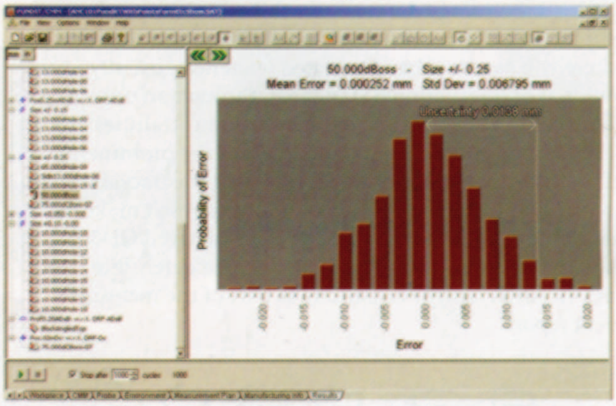


Figure 4. A Distribution of Possible Hole Diameters and Consequent Uncertainty Estimation from an SBC-based CMM Simulation Software Package

Evaluating measurement uncertainties by software simulation means the behavior of different CMMs – operating under otherwise identical conditions – can also be precisely compared to assess their relative abilities to measure any given part, or set of parts. This can help to determine the choice of a new CMM to purchase or to select the right machine for a given job from a stable of CMMs. The user can even see how small his measurement uncertainties might be with a perfect CMM, meaning he can recognize how much uncertainty is contributed by the other factors mentioned above.

Similar experiments based on a perfect sensor, etc., identify the weak link in a measuring system so that resources efficiently focus on improving measurement precision. Simulation software of this sort is an effective means of training CMM operators and programmers in good measurement practice, without tying up valuable CMM time in the process.

K. D. Summerhays is the technical director of MetroSage LLC, 26896 Shake Ridge Road, Volcano, CA 95689, 415-336-2244, Fax: 415-358-6871, www.metrosage.com FM