HAVING CONFIDENCE IN SPECIFICATIONS

David Deaver
Fluke Corporation
PO Box 9090
Everett, WA 98206
425-446-6434
David.Deaver@Fluke.com

***Abstract:** This paper presents some of the challenges in creating instrument specifications from a manufacturer's perspective and some of the difficulties using specifications as an estimate of uncertainty from a user's perspective. Despite the difficulties, specifications are the most common means of determining the Type B uncertainty for the standard when making a GUM (Guide to Uncertainty of Measurement) compliant uncertainty analysis. An explanation is presented for the practice of providing 95% and 99% confidence specifications, warranting only the 99% specifications, and verifying the 99% specifications to 95% confidence.*

THE BASIS OF SPECIFICATIONS

Simply stated, specifications are an implied contract between a buyer and seller of a piece of equipment. The seller expects to be paid if the product performs within its specifications and the buyer expects to receive an instrument which lives up to the promises made in the data sheet. Specifications, however, may or may not be a very good representation of the product's actual performance. The manufacturer considers a number of factors when establishing the specifications:

Actual Instrument Performance

One would hope there is some correlation between the actual performance of an instrument and its specifications. Ideally, the specification would correspond exactly to the uncertainty. To approach the ideal, however, a unique specification would have to be assigned to each instrument, taking into account its actual performance and the operating environment. In practice, this is done by many laboratories when characterizing a standard but is seldom done by the manufacturer.

Manufacturing Yield Targets

Though specifications may be stated with a confidence, typically between 95% and 99.7%, all the points tested on the production line must be measured within the specification limits before the product can be shipped. For a standard resistor, whose value is specified at a 95% confidence level to be within limits centered about the nominal value for the resistor, we could expect to have to re-trim 5% of the standards before they could be shipped. Specifying a complex instrument at the true 95% confidence level for each point would be a manufacturing disaster. For example, each Fluke Model 5520A Multiproduct Calibrator is tested at 552 points on the production line prior to shipment. If each of the points has a 95% probability of being found in tolerance, there would only be a 0.95^{552} = 0.00000000051% chance of finding all the points within the specification limits if the points are independent! Even if we estimate 100 independent points (about 2 per range for each function), we would still have only a 0.95^{100} = 0.6% chance of being able to ship the product. Figure 1 shows the probability of an instrument passing all points tested if the points are independent and if all points have normal probability density distributions with the same confidence interval, 95%, 99%, or 99.7%.

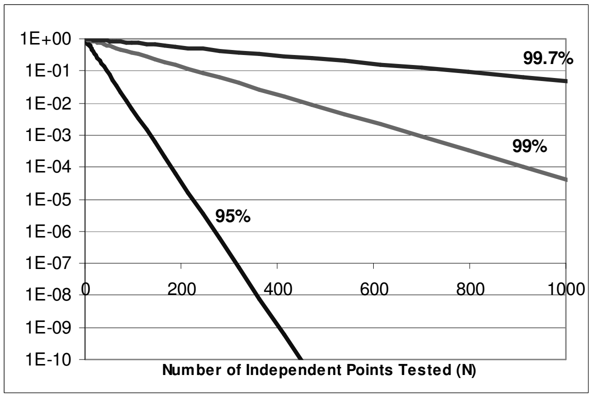

Fig. 1 Probability of all N Points In-Tolerance

For our example of 100 independent points, on average, we would have to design the individual points to a 99.95% confidence level to have 95% confidence that the instrument would pass the complete verification test. Table 1 lists the confidence levels for individual points (P) required for an overall instrument yield (Y) of 95%, 99% and 99.7%.

N	Y=95%	Y=99%	Y=99.7%
1	0.95	0.99	0.997
10	0.995	0.999	0.9997
100	0.9995	0.9999	0.99997
1000	0.99995	0.99999	0.999997

Table 1: Yield for an individual point (P) Such That P^N=Y, the Target Yield

Figure 2 shows the coverage factors applied to the uncertainties at individual points required to maintain the overall target confidence level for an entire instrument. For our example of 100 independent points with equal normal distributions relative to their specification, the coverage factor would increase from 2 to 3.5 to achieve our target yield of 95%.

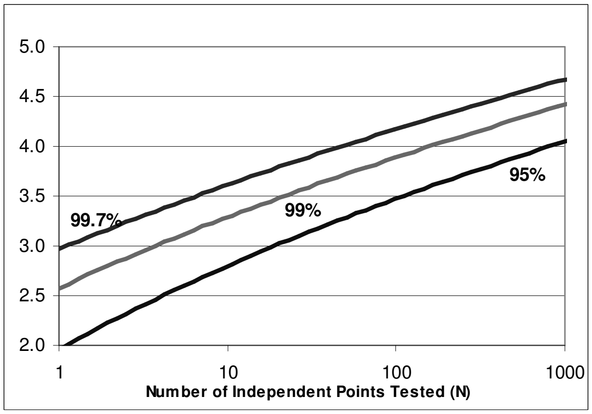

Fig. 2: Individual Coverage Factor to Meet Overall Confidence Target for N Points

Competitive and Market Needs

If there is not a compelling need to make specifications as tight as absolutely possible, there is considerable benefit to the manufacturer to keep them loose in order to enjoy high yields and low warranty costs. Similarly, for the user, it is nice to have higher confidence the unit is performing within the specification limits and enjoy long calibration intervals. Often, however, manufacturers have specsmanship battles with their competitors, each wanting to have the better specifications. And users ask for tighter specs on test equipment to maintain low uncertainties and high TURs (Test Uncertainty Ratios) for their calibrations. As we have seen however, along with tighter specifications comes the adverse impact on the yields, warranty costs, and percent-in-tolerance numbers.

Environmental Conditions

Specifications for an instrument must take into account its operating environment. Though most instruments are specified for a broad temperature range such as 0-50 ºC and a wide humidity range, few actually operate in such adverse conditions. Better performance can be expected if the temperature and humidity are more moderate. In fact, it is common for manufacturers to supply tighter specifications for well controlled environments and more relaxed specifications for those less well controlled. Your environment may be even better controlled than the narrowest ranges specified resulting in better performance than even the best specifications. However, the burden is generally on the user to characterize the instrument to realize the benefit.

STATING THE SPECIFICATIONS

Uncertainties are generally stated at the 95% confidence level. However, it is common for manufacturers of complex instruments to state specifications at higher confidence reflecting the constraints put upon them by yield considerations. They want to convey the conservative nature of the specifications.

Such a statement of confidence level by the manufacturer is actually of significant benefit to the user. When using specifications as an estimate of the uncertainty, the GUMs (Guides to Uncertainty of Measurement) [1] require that, given no additional information, a rectangular distribution within the span of the specification limits be used. Standard uncertainty is computed by taking half the span (the one-sided limit for symmetric limits) divided by √3. If a confidence level is stated at 95%, it is permissible to divide by the coverage factor of 2 assuming a reasonably large number of degrees of freedom. This assumes a normal distribution centered within the specification limits (confidence levels are only defined for normal distributions). When the confidence level is 99%, one may divide by 2.58 resulting in a standard uncertainty only ⅔ as large as the rectangular distribution assumed when no confidence level was stated.

Non-Warranted Specifications

If re-calculating the uncertainties from high confidence specifications is of such great benefit, why don't manufacturers provide the better 95% specifications in the first place? The answer lies back with the earlier discussion of the yield constraint. Specifications are usually warranted. If the manufacturer provides a significantly better specification, significantly higher warranty costs can be expected because there is considerably higher probability some point will be found outside of the specification limits. Consider the previous example. If the specifications are 3.5 times the standard deviation of the actual distributions, we would have an in-tolerance probability of 99.95% for an individual point or 0.9995^{100} = 95% for 100 points. If we tighten the specification by 33% to 2.3 sigma, we would have a confidence level of about 97% for each individual point but only 0.97^{100} = 4.8% chance of all 100 independent test points being in-tolerance. As an aid, some manufactures do provide both 99% and 95% specifications but warrant only the 99% specifications because of the huge yield implications for a complex instrument.

Verifying Specifications

To further complicate matters, when the manufacturer tests the product's warranted (99%) specifications, it does so with a measurement uncertainty stated at the 95% confidence level. This is initially confusing to many users. They would expect the verification tests to be conducted at the same confidence level as the instrument specifications. However, the decisions about what confidence level to claim for the specifications is independent of the confidence level of the verification test. The uncertainties of measurement for the verification should be calculated in the conventional manner, a 95% confidence level per the GUM.

CONCLUSION

Providing a higher confidence level for the specifications wasn't much of an issue a number of years ago when instruments weren't so complex. But the complexity has actually driven instruments to be more conservatively specified. The techniques described in this paper allow the educated user to justify considerably lower uncertainties than the ones obtained by taking the specifications at face value. Hopefully, this also leads to an understanding as to why the manufacturer is reluctant to guarantee them.

REFERENCE

[1] Taylor, B.N. and Kuyatt, C.E., "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results", NIST TN 1297, 1994.