Metrology Consulting, Inc.

METROLOGY INSIGHT

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I probably received more feedback from the last issue of Metrology Insight, than from any other issue. I enjoy knowing that you find Metrology Insight useful.

Metrology Insight is published by HN Metrology Consulting. The purpose of Metrology Insight is to heighten awareness of the details that go into making good metrology and, of course, HN Metrology Consulting as a source of information about these details.

I have been busy lately finishing the conversion of my ISO Guide 25 Model Quality Manual into ISO 17025 format. You will find more details about the manual on page 4.

On page 4 you will also find information about the seminars I teach for Mitutoyo Institute of Metrology. Go to the listed website to find out where and when each seminar is offered.

The main article in this issue of Metrology Insight is developed from a presentation I made to the A2LA assessors at their annual conclave. The article covers the basic steps involved in uncertainty analysis.

There is also a quick tip regarding the proper calculation of repeatability when several readings are involved, as I have received several questions on this issue recently.

I hope you find Metrology Insight useful and educational. If you have a suggestion for a topic or any other comment or suggestion, please do not hesitate to contact me.

\- Henrik Nielsen

HN Metrology Consulting now offers an ISO 17025 compatible Model Quality Manual, see page 4

The Basic Steps in Uncertainty Analysis

Uncertainty budgets can take many different forms and still be technically valid. This article outlines general attributes of uncertainty budgets and the generic steps that one would normally go through in analyzing the uncertainty of a measurement process.

The format chosen for the presentation of the analysis is secondary and can neither save a budget based on a flawed analysis, nor invalidate a budget based on a valid analysis.

One should bear in mind that uncertainty is an attribute of the result of a measurement. Therefore, if a given calibration or test measures several attributes of a standard, measuring equipment or test item, then an uncertainty budget is necessary for each of these attributes.

A valid uncertainty analysis will be based on a variation on the following steps:

1. Specify the Measurand
2. Determine the Measurement Conditions
3. Identify the Uncertainty Contributors
4. Consolidate Uncertainty Contributors
5. Quantify Uncertainty Contributors
6. Convert Uncertainty Contributors to Standard Uncertainty
7. Calculate Combined Standard Uncertainty and Expanded Uncertainty
8. (If necessary) Re-evaluate Significant Components

Specify the Measurand

While this step may seem redundant, it is really the most important of them all. Without a clear understanding of what the objective of the measurement is, it is impossible to analyze the uncertainty.

Especially for complex measurements, it is not necessarily clear what is being measured. For example, in the calibration of a multimeter or a coordinate measuring machine (CMM), there are several separate measurands involved. For the multimeter there may be several measurements of Volts, Amperes and Ohms involved, maybe both for DC and AC (maybe even at different frequencies). For the

CMM there are scale errors, geometry errors, probing errors and various influences from environmental effects. If the laboratory does not understand this, but sees the calibration as a "black box," then it is impossible for the laboratory to analyze the uncertainty of the measurements.

Determine the Measurement Conditions

The measurement conditions are the assumptions that the uncertainty budget is based upon, e.g. the temperature variation in the laboratory. The conditions assumed in the budget must agree with the actual conditions in the laboratory. The degree of control necessary depends on how tight the control of each condition is assumed to be and how significant the resulting uncertainty contributor is.

The measurement conditions include issues such as:

- Uncertainty of the calibration of the standards/ equipment
- Environment
- Operator
- Measuring Object (Item under test)
- Measuring procedure

Measuring uncertainty can normally be traced back to one of the above issues, so identifying them and determining their boundary conditions is the basis for developing a realistic uncertainty budget.

The uncertainty of calibration can either be found in the calibration certificate or the procedure standard which the gage is calibrated to. It may take some investigation and/ or interpretation to get from the value quoted in the certificate to the numbers necessary for the uncertainty calculation, but with common sense and reasonable assumptions it can usually be done.

The environment is often a limiting factor for the accuracy to which a measurement can be performed. For mechanical measurements the temperature is usually a major contributor, but vibration can also play a significant role. For temperature it is important to not only consider stable deviations from reference temperature, but also gradients in space and variations over time which are often the largest contributors.

The operator plays a very significant role especially in manual measurements; whereas operator influence is virtually eliminated in highly automated measurements. Operator influences can come through:

- biased readings
- readings intentionally or unintentionally taken to reduce apparent variation
- reading or writing error
- handling technique

Normally it is difficult to quantify the influence of the operator, except what can be learned from repeatability and reproducibility studies.

The influence from the measuring object comes into play when the measurement has built in assumptions about the measuring object. For example it is generally assumed that the faces of gage blocks are parallel; but if they are not, then it adds to the uncertainty of the measurement. It is mostly in simplified, shop-floor type measurements that this becomes an issue.

The measurement procedure is the tool that is used to control all the other factors and ensures that the limits that are assumed in the uncertainty budget for each of them are valid. A good procedure can minimize the influences primarily from the environment and the operator, but also all the other influences. Consequently a poor measurement procedure can accentuate all the other influences.

All of these issues should be addressed in the uncertainty analysis to some extent. The degree of rigor depends on the measurement and the uncertainty claimed.

Identify the Uncertainty Contributors

The laboratory should have a list of all the contributions they have considered in their uncertainty analysis. The laboratory may not necessarily have conducted detailed studies on all of these contributors (see below), but by documenting what contributors have been considered in the analysis, the laboratory can demonstrate its understanding of the physics behind the measurement process.

Consolidate Uncertainty Contributors

This is an optional step. In many cases, one will find it convenient to consolidate or re-formulate some of the uncertainty contributors identified in the previous step. For example, in a simple diameter measurement, lighting, humidity, vibration, form error of measuring object and operator influence may be consolidated and considered covered by a gage repeatability and reproducibility (GR&R) study. One may find that some effects are double counted as they are included in more than one identified contributor. One may also subsequently decide that some of these contributors are negligible based on available information or know-how.

Quantify Uncertainty Contributors

To quantify the uncertainty contributors, the laboratory must, for example convert the temperature variation in the laboratory into microinches in order to quantify how much the temperature influences a length measurement. In general there will be a law of physics or a statement in equipment manuals or other documentation that explain how one converts an influence in one unit into the unit of the measurand.

Convert Uncertainty Contributors into Standard Uncertainty

In this step each contributor is converted into a value that has the weight of one standard deviation in the unit of the measurand. This value quantifies how much the contributor can influence the result of the measurement and is called the standard uncertainty.

There are two ways of performing this conversion. In a type A estimation, repeated observations are used to calculate the standard deviation. In a type B estimation, prior knowledge, data from specification and calibration certificates and other information is used to substantiate values based on engineering judgment. In a typical type B estimation, a set of variation limits is determined and a distribution between these limits is assumed.

Calculate Combined Standard Uncertainty and Expanded Uncertainty

The combined standard uncertainty is calculated by adding the standard uncertainty for each uncertainty contributor together according to the following (simplified) rules:

- Positively correlated contributors are added linearly
- Negatively correlated contributors are subtracted linearly
- Uncorrelated contributors are added using the square root of the sum of the squares.

It should be noted that the sums (differences) of the correlated contributors are uncorrelated with the rest of the contributors and, therefore, can be added to them using the square root of the sum of the squares method.

The expanded uncertainty, which is the uncertainty quoted e.g. in calibration certificates and test reports, is calculated by multiplying the combined standard uncertainty by a coverage factor, k = 2. The expanded uncertainty has a coverage of approximately 95%

Re-evaluate Significant Components

This is an optional final step. If one is not satisfied with the calculated uncertainty, one can re-evaluate the significant components and, for example, change the temperature control in the laboratory, change calibration interval and tolerances for the equipment or make other changes to reduce the uncertainty.

Assessing the Uncertainty Budget

To assess the validity of an uncertainty budget an assessor would evaluate whether the laboratory has gone through a thinking process along the lines listed above.

Having a table or a software program that lists uncertainty contributors and corresponding values does not constitute an uncertainty budget, without some substantiation that the list of contributors contains all the relevant ones and that the conversion to standard uncertainty has been done correctly.

Consequently, it is only of secondary importance what format or software a laboratory has chosen to use to document the uncertainty budgets. What is of primary importance is the analysis of the measuring processes.

Quick Tip: The Repeatability of a Mean Value

One "trick" to reduce the uncertainty of a measurement is to take several readings and average. Especially when the repeatability is one of the main contributors, this can reduce the uncertainty significantly.

In general, the standard deviation of the mean of N repeated measurements is equal to the standard deviation of each individual measurement divided by the square root of N:

$$\sigma_{average} = \frac{\sigma_{individual}}{\sqrt{N}}$$

The question is what value can be used for N? If, for example, the standard deviation is determined by a study involving 60 indvidual readings, but the values reported in the actual measurements each is based on an average of 3 readings, then the correct value for *N* is 3. The number of readings involved in determining the standard deviation (60) is not relevant for this calculation.

Consequently, in the most common case where the actual measurement is only based on one reading, you do not get to divide by anything, regardless of how many reading were involved in the repeatability study.

New from HN Metrology Consulting: An ISO/IEC 17025 compatible model quality manual.

As reported in the last issue of Metrology Insight, ISO/IEC 17025 has replaced ISO/IEC Guide 25 as the document specifying the requirements for accredited laboratories. While there is a two year conversion period, both laboratories that are currently accredited and new laboratories seeking accreditation are working hard to make their quality system ISO/IEC 17025 compliant.

In their search for help with these issues many laboratories turn to the ISO/QS 9000 community. The result is often an adapted ISO/QS 9000 quality system that does not really fit the requirements of ISO/IEC 17025, is difficult to work with and leaves the laboratory vulnerable at assessments.

Using the thorough understanding of these challenges I have gained through my work as an accreditation assessor, I have developed an ISO/IEC 17025 compatible model quality manual with all the related quality policies and procedures, as well as numerous support documents.

Contact HN Metrology Consulting for more information about the model quality manual, how it can be adapted to cover your specific needs and how I can help you in your work towards accreditation.

Training from HN Metrology Consulting:

HN Metrology Consulting offers in-house training seminars on metrology, measurement uncertainty and quality assurance for calibration laboratories.

The following 2 day seminars are available at short notice and can be tailored to your specific needs:

- **Managing Measurement Uncertainty**
- **Quality Assurance to ISO Guide 25**

Contact HN Metrology Consulting for more information on these seminars and to request the brochure.

Seminars I teach through the Mitutoyo Institute of Metrology:

The following are very intense 1 day seminars. They cover a lot of material in a very short time.

- **Estimating Measurement Uncertainty**

  This seminar is very popular and has been offered since early 1999.

- **How to clear ISO Guide 25 for your in-house laboratory**

  I have had very good response to this seminar, it has been offered since this spring.

Go to the Mitutoyo Institute of Metrology website at: www.mitutoyo.com/metclass/semsche/semsch.htm to find out when the seminars are offered in your area. New seminars are scheduled every month. You can also call (630) 978 6469 for more information, to sign up for a seminar or to check availability in your area.

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