Uncertainty measurement in destructive testing

Dascau H.[1]
[1] ISIM Timisoara
(hdascau@isim.ro)

Abstract

In the activity of a destructive testing laboratory, the examination reports in which the conditions and results of measurements are mentioned must contain information on the measurement uncertainties of these results. Knowledge of measurement uncertainties is very important because, a series of elements are established, e.g.: functionality of pieces, life span of pieces, evolution of a defect in a piece etc. Destructive test methods provide a measured value of a specific property, for a material or product. The measured single determination is a fixed value but has also a random variability associated with it. If the destructive test is repeated once again, it will produce a slightly different result. If a different operator at a different destructive lab also performs the same test, his results will have an even larger variability associated with them. This variability shall be understood as being valis, for all test methods that are used. Why measuring and presenting this variability information? Why is this information important to be known? What information could be misleading?

Introduction

According to ISO/IEC 17025, testing laboratories shall report the estimated uncertainty of measurement, where applicable, under the following circumstances:
(a) when the information on uncertainty is relevant to the validity or application of the tests results
(b) when it is required by the client
(c) when the uncertainty affects compliance to a specification limit i.e., the interpretation of the results could be compromised by a lack of knowledge of the uncertainty.

The Guide to the Expression of Uncertainty in Measurement (GUM) developed by ISO, has adopted the approach of grouping uncertainty components into two categories based on their methods of evaluation, '**Type A**' and '**Type B**'.

- '**Type A**' evaluation is done by calculation from a series of repeated observations, using statistical
- methods.
- '**Type B**' evaluation is done by means other than that used for '**Type A**'. For example, based on data in calibration certificates, previous measurement data, experience with the behavior of the instruments, manufacturers' specifications or any other relevant information.

Components of uncertainty are evaluated by the appropriate method, and each is expressed as a **standard deviation** and is referred to as a **standard uncertainty**.
The standard uncertainty components are combined to produce an overall value of uncertainty, known as the **combined standard uncertainty**.

An **expanded uncertainty** is usually required to meet the client's or regulatory requirement. It is intended to provide a greater interval about the result of a measurement than the standard uncertainty with, consequently, a higher probability that it encompasses the value of the measurand.

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It is obtained by multiplying the combined standard uncertainty by a **coverage factor**, *k*. The choice of factor is based on the coverage probability or **level of confidence** required.

Measurement uncertainty is calculated considering a number of sources of errors thar might affect the measurement to highlight the contribution of each of them on the final result and on the total measurement uncertainty. The terms "error" and "uncertainty" should not be confused because, although they seem similar, they represent different concepts. Errors are those that affect the measurement, bringing changes to the final outcome, whereas uncertainty is the one that quantifies the accuracy with which the measurement result was determined. Errors of measurement have two components, a random component and a systematic component. Uncertainties arise from random effects and from imperfect correction for systematic effects

Some examples of uncertainty measurement sources are given below:
(a) Sampling - the sample may not be fully representative
(b) Personal bias in reading analogue instruments
(c) Instrument resolution or discrimination threshold, or errors in graduation of a scale
(d) Uncertainty values assigned to measurement instruments, reference standards and reference materials
(e) Instrument drifting - changes in the characteristics or performance of a measuring instrument since the last calibration
(f) Variations in repeated observations made under apparently identical conditions – such random effects may be caused by, for example, short term fluctuations in local environment (temperature, humidity and air pressure), variability in the performance of the operator

These sources are not necessarily independent. Certain systematic effects may exist that cannot be considered though it contributed to the error.
Such effects may be difficult to quantify and may be evident from examination of proficiency testing results, e.g., strain rate effect on tensile test result.
A destructive testing laboratory shall at least estimate all components of uncertainty and make a reasonable estimation. The degree of rigor required in an estimation of measurement uncertainty depends primarily on the use of the test results and laboratory should ensure that the degree of rigor meets the client’s requirements.
Minor components that have been disregarded may need to be re-considered when a more rigorous estimation of measurement is required.
Measurement uncertainty may need to be reviewed and revised when there are changes in the laboratory such as environmental conditions, equipment, calibration grading, personnel, etc.

The Six Steps to Determining Uncertainty of Measurement

1. Make a model of the measurement system.
2. List all the sources of uncertainties.
3. Calculate the standard uncertainties for each component using type A analysis for those with repeated measurements and type B for others.
4. Calculate the sensitivity coefficients.
5. Calculate the combined uncertainty, and, if appropriate its effective degrees of freedom.
6. Calculate the expanded uncertainty. Use a calculated coverage factor. Round the measured value and the uncertainty to obtain the reported values.

ISO/IEC 17025 does not specify any particular approach to estimate measurement uncertainty. All approaches that give a reasonable estimate and are considered valid within the relevant technical discipline are equally acceptable.

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The following are examples of possible approaches for uncertainty measurement:

- The Guide to the Expression of Uncertainty in Measurement (GUM)
- ISO/TS 21748.

The extent of the information given when reporting the result of a test and its uncertainty shall be related to the requirements of the client, the specification and the intended use of the result. The following information should be available either in a report or in the records of the test or both:
(a) method used to calculate the uncertainty of the results
(b) list of uncertainty components and documentation to show how these were evaluated, e.g., record of any assumptions made, and the sources of data used in the estimation of the components
(c) sufficient documentation of the steps and calculations in the data analysis to enable a verification of the calculation if necessary
(d) all corrections and constants used in the analysis, and their sources.

When reporting the result and its uncertainty, the use of excessive number of digits should be avoided. It usually suffices to report uncertainty estimates to no more than two significant figures (although at least one more significant figure should be used during the stages of estimation and combination of uncertainty components in order to minimize rounding errors).

The uncertainty of measurement is obtained by multiplying the combined standard uncertainty by an appropriate coverage factor, k, which is estimated from Student t-distribution table with known degree of freedom and corresponding level of confidence.
It is a widely held view that, for most measurement systems, the approximation to a normal distribution of the combined uncertainty is reliable up to two standard deviations, but beyond that the approximation is less reliable. This corresponds to a 95% confidence level.

The result of the measurement should be reported together with the expanded uncertainty and coverage factor appropriate to the level of confidence.
In some cases, where a particular factor or factors can influence the results and the magnitude cannot be either measured or reasonably assessed, the statement will need to include reference to this fact.
The destructive testing report shall also state whether sampling and/or sub-sampling is carried out by the laboratory. Where sampling / sub-sampling is carried out by the laboratory, the report shall state whether this sampling / sub-sampling uncertainty is included in the expanded uncertainty.

Certainly, it is worthwhile giving some attention to the anticipated measurement uncertainty before performing tests, so that the number of results that fall in the region of uncertainty is minimized. The traditional rule of thumb employed is to use a measurement system capable of measuring with an uncertainty of 1/10 of the specification limit. This ratio is called the Test Uncertainty Ratio (TUR). Its principal use has been in providing a rationale for selection of test equipment without undertaking a complete analysis of the measurement system.

Many laboratories implement the ISO/IEC 17025 to underpin their competence. Producers of certified reference materials implement in many cases both ISO/IEC 17025 and ISO 17034 for the same purpose.
In proficiency testing, the requirements for demonstrating competence are laid down in ISO/IEC 17043. These standards have in common, among others, that measurement uncertainty shall be evaluated and as appropriate be expressed. Issuing certified reference materials (CRMs) with property values without uncertainty is not permitted according to ISO 17034, as it would for the user be impossible to make a proper assessment of the quality of its result when using the CRM for quality control, nor would it be possible to propagate it when using the CRM in calibration.

Conclusion

As it could be seen the measurement of uncertainty is a complex process. The use of software can be essential for destructive testing laboratories that perform uncertainty calculations. Most of the specialists rely on self-developed spreadsheets or on the laboratory information management system, to perform relevant calculations. Such software systems are not yet been designed for the specific calculations necessary to evaluate, propagate and express measurement uncertainty.

Some examples can be implemented by use of general purpose software, the use of MATLAB or other commercial software. In all cases, the choice for one software package, does not imply that it could not have been done in another software. The same is also related for the selection of libraries and other resources, in the calculation of the uncertainty of measurements.

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