



ACCREDITATION SCHEME FOR LABORATORIES

Guidance Notes NDT 001

Guidance Document for Estimation of Measurement Uncertainty in Non- Destructive Testing

1. General Requirements

- 1.1 It is SAC-SINGLAS policy to apply the requirements concerning the estimation and reporting of uncertainties in accordance with **ISO/IEC 17025**. SAC-SINGLAS approach to evaluating and expressing uncertainties in testing is based on the recommendations of the ISO “**Guide to Expression of Uncertainty in Measurement**” (GUM).
- 1.2 **ISO/IEC 17025** requires all laboratories to report the estimated uncertainties of calibrations on calibration certificates and, where relevant, the uncertainty of test results in test reports and test certificates. Relevant circumstances are:
- (a) where a client’s instructions require a statement of uncertainty;
 - (b) where it is required by the specification calling up the test;
 - (c) where the uncertainty is relevant to the validity or application of the result; e.g. where the uncertainty affects compliance to a specification limit. (Please refer to Section 7 for guidance on this case.)

2 General Principle

- 2.1 The objective of a measurement is to determine the value of the **measurand**, i.e. the specific quantity subject to measurement. When applied to testing, the general term measurand may cover many different quantities, e.g. the strength of a material, the level of noise measurement, the quantity of gamma radiation for soil density measurement, the size of defects in welds by an ultrasonic NDT and the fire resistance period of doors subject to fire testing, etc. A measurement begins with an appropriate specification of the measurand, the generic method of measurement and the specific detailed measurement procedure.
- 2.2 In general, no measurement or test is perfect and the imperfections give rise to **error of measurement** in the result. Consequently, the result of a measurement is only an approximation to the value of the measurand and is only complete when accompanied by a statement of the **uncertainty** of that approximation.
- 2.3 **Errors** of measurement may have two components, a **random** component and a **systematic** component. Uncertainties arise from random effects and from imperfect correction for systematic effects.

- 2.4 **Random errors** arise from random variations of the observations (random effects). Every time a measurement is taken under the same conditions, random effects from various sources affect the measured value. A series of measurements produces a scatter around a mean value. A number of sources may contribute to variability each time a measurement is taken, and their influence may be continually changing. They cannot be eliminated but the uncertainty due to their effect may be reduced by increasing the number of observations and applying statistical analysis.
- 2.5 **Systematic errors** arise from systematic effects, i.e. an effect on a measurement result of a quantity that is not included in the specification of the measurand but influences the result. These remain unchanged when a measurement is repeated under the same conditions, and their effect is to introduce a displacement between the value of the measurand and the experimentally determined mean value. They cannot be eliminated but may be reduced; e.g. a **correction** may be made for the known extent of an error due to a recognized systematic effect. If no corrections are applied to the measurement, the difference between true value and measured value can be considered as an uncertainty component.
- 2.6 The **GUM** has adopted the approach of grouping uncertainty components into two categories based on their methods of evaluation, '**Type A**' and '**Type B**'.
- 2.7 '**Type A**' evaluation is done by calculation from a series of repeated observations, using statistical methods.
- 2.8 '**Type B**' evaluation is done by means other than that used for '**Type A**'. For example, by judgment based on data in calibration certificates, previous measurement data experience with the behavior of the instruments, manufacturers' specifications or all other relevant information.
- 2.9 Component uncertainties are evaluated by the appropriate method and each is expressed as a **standard deviation** and is referred to as a **standard uncertainty**, through a division of an appropriate factor.
- 2.10 The component standard uncertainties are combined to produce an overall value of uncertainty, known as the **combined standard uncertainty**.
- 2.11 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. 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.

3 Sources of Uncertainty

3.1 There are many possible sources of uncertainty in testing, the main ones include:

- (a) Sampling – the sample may not be fully representative;
- (b) Readability – personal bias in reading analogue instruments, instrument resolution or discrimination threshold, or errors in graduation of a scale;
- (c) Instrument calibration – uncertainty values assigned to measurement instruments, reference standards and reference materials;
- (d) Instrument drifting – changes in the characteristics or performance of a measuring instrument since the last calibration;
- (e) Repeatability – variations in repeated observations made under apparently identical conditions – such random effects may be caused by, for example, variability in the performance of the tester.

4 Reasons for Estimating Uncertainty

4.1 The uncertainty of the result of a test needs to be taken into account when interpreting in certain circumstances. For example, comparison of results from different batches of material will not indicate real differences in properties or performance if the observed differences could simply be within the range of the inherent variation in the test procedure. The uncertainty of a result is a quantitative indication of its quality.

4.2 In some cases the uncertainty in a measurement or test result may be considered to be so small as to be not worth formal evaluation. However, without a formal estimate, this consideration remains intuitive and, when challenged, a convincing response is not possible.

4.3 Systematic assessment of the factors influencing the results and of the uncertainty based on the understanding of the principles of the method and practical experience of its application can be a key part of a method validation.

4.4 An estimation of the components contributing to the overall uncertainty of a measurement or test result provides a means of establishing that the measurement capability of the equipment used is sufficient for valid measurements and results to be obtained.

4.5 A consideration of uncertainty components may also indicate aspects of a test to which attention should be directed to improve procedures.

5 Estimation of Uncertainties

5.1 Uncertainty Components

5.1.1 The total uncertainty of a measurement is a combination of a number of component uncertainties. Even a single instrument reading may be influenced by several factors. Careful consideration of each measurement involved in the test is required to identify and list all the factors that contribute to the overall uncertainty. This is a very important step and requires a good understanding of the measuring equipment, the principles and practice of the test and the influence of environment.

5.1.2 The next step is to quantify component uncertainties by appropriate means. An initial approximate quantification may be valuable in enabling some components to be shown to be negligible and not worthy of more rigorous evaluation. In most cases, a practical definition of negligible would be a component that is not more than a tenth of the magnitude of the largest component. Some components may be quantified by calculation of the standard deviation from a set of repeated measurements (**Type A**) as detailed in the **GUM**. Quantification of others will require the exercise of judgment, using all relevant information on the possible variability of each factor (**Type B**). For '**Type B**' estimations, the pool of information may include:

- a) previous measurement data;
- b) manufacturer's specifications;
- c) data provided in calibration certificates;
- d) uncertainties assigned to reference data taken from handbooks;
- e) experience with or general knowledge of the behavior and properties of relevant materials and instruments; estimations made under this heading are quite common in many fields of testing.

5.1.3 Subsequent calculations will be made simpler if, wherever possible, all components are expressed in the same way, for example, either as a proportion (**percent (%)** or **parts per million (ppm)**) or in the **same units** as used for the reported result.

5.2 Standard Uncertainty

5.2.1 The standard uncertainty is defined as the uncertainty of the result of a measurement expressed as a standard deviation. Expressing all component uncertainties as one standard deviation may minimize the potential for mistakes at a later stage of the evaluation. This may require adjustment of some uncertainty values, such as those obtained from calibration certificates and other sources that often will have been expressed to a higher level of confidence, involving a multiple of the standard deviation.

5.3 Combined Standard Uncertainty

- 5.3.1 The component uncertainties have to be combined to produce an overall uncertainty using the procedure set out in the GUM. In most cases, this reduces to taking the square root of the sum of the squares of the component standard uncertainties (the **root sum square method**). However, some components may be interdependent and could, for example, cancel each other out or could reinforce each other. In many cases this is easily seen and the interdependent components may be added algebraically to give a net value. However, in more complex cases more rigorous mathematical methods may be required for such 'correlated' components. This may call for **partial differentiation** of the mathematical model of the measurands in order to determine the sensitivity coefficients. The **GUM** contains the details of this mathematical derivation.

5.4 Expanded Uncertainty

- 5.4.1 In most cases, it is necessary to quote an expanded uncertainty and the combined standard uncertainty therefore needs to be multiplied by the appropriate **coverage factor, k**. This must reflect the **level of confidence** required, and, in strict terms, will be dictated by the details of the probability distribution characterized by the measurement result and its combined standard uncertainty. However, the extensive computations required to combine probability distributions are seldom justified by the extent and reliability of the available information. In many cases, an approximation is acceptable provided that the probability distribution can be assumed to be normal and that **a value of 2** for the coverage factor defines an interval having a **level of confidence** of approximately **95%**

6 Method of Reporting Test Results

- 6.1 The extent of the information given when reporting the result of a test and its uncertainty should 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) methods used to calculate the result and its uncertainty;
 - b) list of uncertainty components and documentation to show how they were evaluated, e.g. a 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 repeat of the calculation if necessary;
 - d) all corrections and constants used in the analysis, and their sources.
- 6.2 When reporting the result and its uncertainty, the use of excessive numbers of digits should be avoided. Depending on situations, the uncertainty needs not be expressed to more than two significant figures, or sometimes one significant figure may be adequate. At least one more figure should be retained during the stages of estimation processes in

order to minimize rounding errors. The reporting format of test results may be dictated by a test standard. Nevertheless, the last digit of the reported uncertainty value should be in a manner consistent with the format of the same last digit of the test result.

- 6.3 Unless otherwise specified by the client, the result of the measurement should be reported, together with the **expanded uncertainty** appropriate to the **95% level of confidence**, in the following manner:

Measured Value	78.2 (units)
Expanded Uncertainty	± 0.7 (units)
Or	
Measured Value	78.2 (units)
Expanded Uncertainty	± 0.9 (%)

The reported uncertainty is an expanded uncertainty with a coverage factor of $k=2$, which provides a level of confidence of approximately 95%.

- 6.4 In some cases, where a particular factor or factors can influence the results, but where the magnitude cannot be either measured or reasonably assessed, the statement will need to include reference to that fact, for example:

The reported uncertainty is an expanded uncertainty with a coverage factor of $k=2$, which provides a level of confidence of approximately 95% but excluding the effect of.....

- 6.5 Many of the construction materials testing involved unit samples delivered by the client to the laboratory without any sampling, e.g., steel plates, steel rebars, etc. If this is the case, it should be stated in the test report when reporting uncertainty. For example, a statement such as “**unit samples delivered by the client to laboratory**”, “**sample tested as received**” or “**unit specimen tested**” and “**sampling uncertainty is not included in the expanded uncertainty**” should be stated in the report.

7 Assessment of Compliance with Specification

- 7.1 ISO/IEC 17025 requires that, when a test is carried out to a stated specification and the client or the specification requires a statement of compliance, the report must contain a statement indicating whether the results show compliance with the specification. There are a number of possible cases where the uncertainty has a bearing on the compliance statement and these are examined below.

- 7.2 **Approach 1:** The simplest case is to clearly state that the measured result, extended by the uncertainty at a given level of confidence, shall not fall outside a defined limit or limits. In this case, assessment of compliance would be straightforward.

- 7.3 **Approach 2:** The checking of compliance of the test result against a defined limit or limits, no reference is made on the effect of uncertainty for the assessment of compliance. In such case, it may be appropriate for the user to make a judgment of compliance, based on whether the result is within the specified limits, with no account taken of the uncertainty. This is often referred to as 'shared risk', since the end-user takes some of the risk that the product may not meet the specification.
- 7.4 Either approach used should be agreed between the laboratory and its client or should be so instructed by the client, prior to testing. The agreement and/or instruction to reporting a testing uncertainty in a test certificate or report should be clearly stated in the appropriate contractual specification.
- 7.5 By default, the laboratory should not report the expanded uncertainty in a test certificate or report unless it is so required by its client.

8 Work Examples on the Computation of Measurement Uncertainty

- 8.1 Various work examples are attached in the appendices to provide guidance on the computation of measurement uncertainty.

UNCERTAINTY ESTIMATION IN ULTRASONIC THICKNESS MEASUREMENTS OF STEEL PLATES UP TO 25 MM USING A DIGITAL THICKNESS METER

1. Sources of Uncertainty

A. Calibration Block:

Standard uncertainty in dimensions (Type B)
(as shown in calibration certificates) U_1 ± 0.05 mm

B. Instrument (digital ultrasonic thickness meter):

(i) Linearity of time base (Type B) U_2 ± 0.05 mm

(ii) Readability/resolution of display unit (Type B) U_3 ± 0.01 mm

(ii) Zero adjustment (Type B) U_4 ± 0.01 mm

C. Temperature variations (0 to +50 °C) (Type B) U_5 ± 0.007 mm
{ α (steel) = 11×10^{-6} °C⁻¹, $\Delta T = \pm 25$ °C, $L = 25$ mm}

D. Random variations in the readings (Type A) U_6 $\pm u_6$ mm
(due to instability of instrument readings,
operator error in reading, etc.)

2. Estimation of the Uncertainties

(i) Standard uncertainty of dimensions of calibration block $u_1 = \frac{U_1}{k}$

(ii) Standard uncertainty of linearity of time base $u_2 = \frac{U_2}{k}$

(iii) Readability/resolution of display unit of instrument $u_3 = \frac{U_3}{\sqrt{3}}$

(iv) Standard uncertainty in zero adjustment $u_4 = \frac{U_4}{k}$

(v) Standard uncertainty due to test temperature variations $u_5 = \frac{U_5}{k}$

(vi) Uncertainty in instrument readings due to
standard deviation (SD) of n measurements $u_6 = \frac{SD}{\sqrt{n}}$

3. Combined standard uncertainty

$$u_c^2 = u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2 + u_6^2 = \sum u_i^2$$

4. Estimated expanded uncertainty

$$U_e = k u_c$$

5. Assuming the measurements are made with 95 % confidence level, set $k = 2$.

EXAMPLE: Estimation of error of measurements made on the thickness of a steel plate of nominal thickness 10 mm. Five thickness measurements 10.45, 10.20, 10.00, 9.83 and 9.55 mm are made using a digital ultrasonic thickness meter having a resolution of 0.01 mm.

$$u_1^2 = (0.05 / 2)^2 = 0.000625$$

$$u_2^2 = (0.05 / 2)^2 = 0.000625$$

$$u_3^2 = (0.01 / \sqrt{3})^2 = 0.000033$$

$$u_4^2 = (0.01 / 2)^2 = 0.000025$$

$$u_5^2 = (0.007 / 2)^2 = 0.000012$$

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n=5} x_i = \frac{1}{5} (10.45 + 10.20 + 10.00 + 9.83 + 9.55) = \frac{50.03}{5} = 10.01$$

$$SD = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n=5} (x_i - \bar{x})^2}$$

$$= \sqrt{\frac{1}{4} [(10.45 - 10.01)^2 + (10.20 - 10.01)^2 + (10.00 - 10.01)^2 + (9.83 - 10.01)^2 + (9.55 - 10.01)^2]}$$

$$= \sqrt{\frac{1}{4} [0.1936 + 0.0361 + 0.0001 + 0.0324 + 0.2116]} = \sqrt{0.11845} = 0.3442$$

$$u_6 = \frac{SD}{\sqrt{n}} = \frac{0.3442}{\sqrt{5}} = 0.153931$$

$$u_6^2 = 0.023695$$

$$u_c^2 = \sum_{i=1}^6 u_i^2 = 0.000625 + 0.000625 + 0.000033 + 0.000025 + 0.000012 + 0.023695 = 0.025015$$

$$u_c = \sqrt{0.025015} = 0.158162$$

$$U_e = k u_c = 2 \times 0.158162 = 0.316304 = 0.32 \text{ mm}$$

$$\therefore \text{The final plate thickness} = \bar{x} \pm U_e = 10.01 \pm 0.32 \text{ mm}$$

Note : The example is formulated based on a flat steel plate and at ambient temperature. Users are to determine the effect on measurement uncertainty for difference in shape and temperature.