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TECHNICAL REPORT

Aspects and understanding of measurement uncertainty – Background information on measurement uncertainty based on the example of IEC TC 85 (Measuring equipment for electrical and electromagnetic quantities)

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IEC TR 63519 has been prepared by IEC technical committee TC 85: Measuring equipment for electrical and electromagnetic quantities. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
85/918/DTR	85/927/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

ASPECTS AND UNDERSTANDING OF MEASUREMENT UNCERTAINTY –

Background information on measurement uncertainty based on the example of IEC TC 85 (Measuring equipment for electrical and electromagnetic quantities)

1 Scope

This document provides information on terminology and general concepts in the determination of measurement uncertainties (MU). It focuses on application aspects based on the example of IEC TC 85 (Measuring equipment for electrical and electromagnetic quantities) and shows the opportunities and implications for further use of measurement uncertainties.

Measurement uncertainties are relevant for metrological compatibility and metrological traceability. Therefore, information on the role of measurement uncertainty in decisions or conformity assessments is given.

References to documents, standards and guidelines are made but only key results will be stated.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
probability distribution
function giving the probability that a random variable takes any given value or belongs to a given set of values

[SOURCE: IEC 60050-103:2009, 103-08-07]

3.2
distribution function
function f of the argument x giving the probability $f(x)$ that the value ξ of a random variable be less than or equal to the value x, i.e. the probability that $\xi \leq x$

[SOURCE: IEC 60050-103:2009, 103-08-08]

3.3

probability density
probability density function
PDF
for the distribution function f of the argument x, derivative $\mathrm{d}f(x) / \mathrm{d}x$

[SOURCE: IEC 60050-103:2009, 103-08-09]

3.4

calibration
set of operations which establishes, by reference to standards, the relationship which exists, under specified conditions, between an indication and a result of a measurement

Note 1 to entry: This term is based on the "uncertainty" approach.

Note 2 to entry: The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram.

[SOURCE: IEC 60050-300:2001, 311-01-09]

3.5

metrological compatibility of measurement results
metrological compatibility
property of a set of measurement results for a specified measurand, such that the absolute value of the difference of any pair of measured quantity values from two different measurement results is smaller than some chosen multiple of the standard measurement uncertainty of that difference

Note 1 to entry: Metrological compatibility of measurement results replaces the traditional concept of 'staying within the error', as it represents the criterion for deciding whether two measurement results refer to the same measurand or not. If in a set of measurements of a measurand, thought to be constant, a measurement result is not compatible with the others, either the measurement was not correct (e.g. its measurement uncertainty was assessed as being too small) or the measured quantity changed between measurements.

Note 2 to entry: Correlation between the measurements influences metrological compatibility of measurement results. If the measurements are completely uncorrelated, the standard measurement uncertainty of their difference is equal to the root mean square sum of their standard measurement uncertainties, while it is lower for positive covariance or higher for negative covariance.

[SOURCE: ISO/IEC Guide 99:2007, 2.47]

4 Role of the measurement uncertainty

4.1 General

Measurements are subject to influences. Although a single value is measured, the result is an interval of possible values. The measurement uncertainty comes into place in order to define the limits of this interval and give a number to this imperfection.

EXAMPLE Measurement of a voltage of 1 V with a resolution of 1 mV on a digital display. Reading a value of 1,000 V would lead to an interval from 0,999 50 V to 1,000 49 V if only the resolution is considered (see Figure 1). The reading of 1,000 V is in the middle of the interval with a width given by the resolution. It is assumed that the resolution of the display corresponds to the last significant digit of the device.

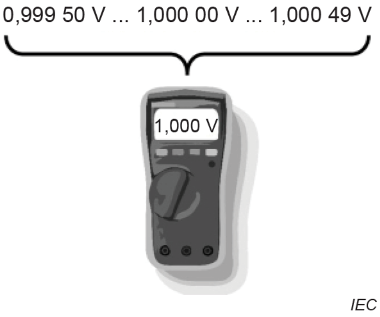

Figure 1 – Measurement of a voltage of 1 V with a resolution of 1 mV on a digital display

When it comes to the determination of the measurement uncertainty, the Guide to the expression of uncertainty in measurement (GUM, [ISO/IEC GUIDE 98-3:2008]) represents a statistical approach with the possibility to combine different influence quantities. The GUM requires the knowledge of the probability density function (PDF, see 3.3) of those influence quantities. It is not always possible to determine or even know all influence quantities together with their PDF. However, the analysis of the measurement process will consider at least the most dominant ones. Otherwise, it is not possible to have a reliable result for the measurement uncertainty.

EXAMPLE For displaying devices, the resolution is an influence quantity. Its PDF is given by a rectangular (uniform) distribution, since all values in the interval are equally probable (see Figure 2).

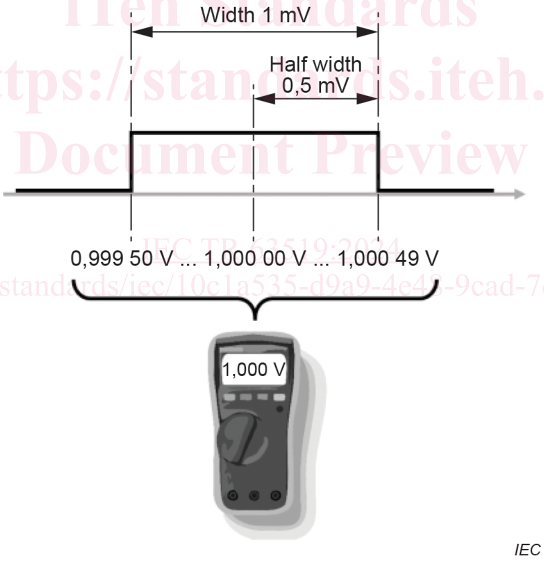

Figure 2 – Rectangular (uniform) distribution for the resolution when measuring a voltage of 1 V with a resolution of 1 mV on a digital display

The measured quantity is a function of the influences, and since each influence quantity has an associated PDF, the measured quantity itself is described by a PDF. Typically, this PDF is considered to be a normal distribution[1]. The normal distribution is characterized by its most probable value (e.g. measured value) and its standard deviation (std. dev.). The latter is a measure of the variation and thus also of the width of this normal distribution. The measurement uncertainty is expressed in multiples (coverage factor) of the standard deviation (see Figure 3). Usually, a coverage factor of $k = 2$ is used as this corresponds to a confidence level of approximately 95 %.

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[1] According to the central limit theorem, the linear summation of an infinite number of arbitrary PDF (thus also rectangular distributions) ends up in a normal distribution. The normal distribution is also known as Gaussian distribution.

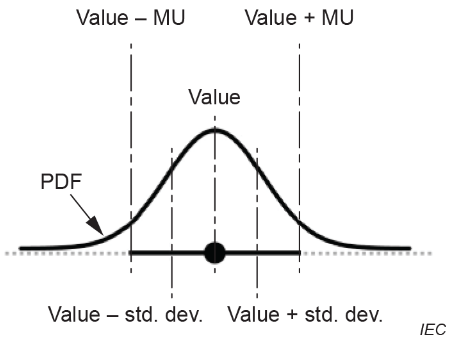

Figure 3 – Value and assigned measurement uncertainty (MU) together with its probability density function (PDF)

Expressions like specification, tolerance, class, precision, error, maximum permissible error or accuracy usually do not provide any information about the underlying shape of a PDF. Moreover, the measurement uncertainty is always assigned to a measured value and manifests the conditions (e.g. measuring process, environmental conditions, impacts of the measuring person) that lead to the measured value, whereas specifications or tolerances are assigned to a device or system and do not change. This means specifications or tolerances represent fixed limits (e.g. guaranteed by a manufacturer or defined by a standard) and the position with respect to these limits of the measured value, together with its measurement uncertainty, can be used for further decisions (see 4.3).

4.2 Compatibility

Without the consideration of the measurement uncertainty, two measurement results will be in agreement only if the two numbers are the same digit by digit. Therefore, the compatibility of two different measured values for the same measurement is not obvious. As pointed out earlier, every measurement value has its measurement uncertainty. This means the result of a measurement is a range of possible values rather than a single value. An agreement can be achieved if the two measured values are (metrological) compatible (see 3.5) with respect to their measurement uncertainties, i.e. the two ranges overlap. The larger the overlap, the higher the probability that the two results comply.

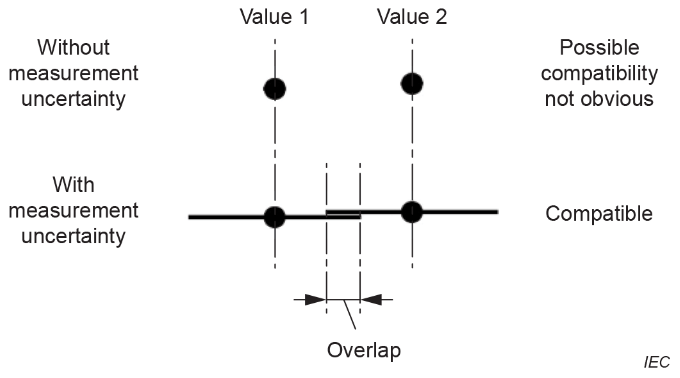

Figure 4 – Compatibility of two measured values with or without measurement uncertainty

A graphical comparison of the overlap as shown in Figure 4 can support a general understanding of the topic but does not reflect statistical considerations.

Typically, this comparison is done mathematically through defined quality factors that consider the statistical properties of the measurement uncertainties (e.g. coverage factor, confidence level and correlations).