USING OF UNCERTAINTIES ESTIMATION IN INTERNATIONAL STANDARDS

Oleh Velychko

State Enterprise "Ukrmetrteststandard", Metrologichna Str., 4, 03680, Kyiv-143, Ukraine
Tel. / Fax + 38 (044) 526 0335, Velychko@ukrcsm.kiev.ua

Abstract **–** Peculiarities of uncertainty estimation in GUM and IEC international standards are shown. The correct use of GUM for expression of measurements uncertainty in development of new and reconsideration of old international standard is recommended.

I. Introduction

The uncertainty of the result of a measurement reflects the lack of exact knowledge of the value of the measurand. The result of a measurement after correction for recognized systematic effects is still only an estimate of the value of the measurand because of the uncertainty arising from random effects and from imperfect correction of the result for systematic effects (GUM, 3.3) [1]. The total uncertainty of a measurement, in general, depends on the instrument, the environment, the procedures used, the skill of the operator, data reduction (round-off procedures, algorithms used, etc.), and other elements. Measurement uncertainty relates to the measurement process, not only to the instrument itself (OIML D 16, 3.1) [2].

GUM focused on the mathematical treatment of measurement uncertainty through an explicit measurement model under the assumption that the measurand can be characterized by an essentially unique value. Moreover, in the GUM as well as in IEC documents, guidance is provided on the uncertainty approach in the case of a single reading of a calibrated instrument, a situation normally met in industrial metrology.

II. General approach

Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by experimental standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

Modern instrumentation depends ever more on sophisticated elaboration of signals inside the instrument, and the measuring instruments that are a part of automatic control or regulation chains do not even present indications readable on a scale. A terminology suited to all kinds of instruments and able to avoid misunderstandings shall distinguish clearly between the descriptions of the output of the instrument: the indication allows knowing the measurement result through the calibration of the instrument.

The definition of uncertainty calls for a readjustment of several terms concerning the calibration of instruments, because the statement that to a measurand can be reasonably attributed a dispersion of values makes obsolete the traditional definitions that treat the result of a measurement as a single value and the calibration as an additive correction of the indicated value.

Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes known systematic effects are not corrected for but are instead treated as uncertainty components.

The uncertainty of a valid result of a measurement shall be such as to ensure compatibility with all other valid measurements of the same measurand, the compatibility being judged by the overlapping of the

numerical sets representing the results. This criterion of compatibility comes out by applying the GUM criteria for the combination of uncertainties to the uncertainty of the difference between two results.
In the GUM, the definitional uncertainty is considered to be negligible with respect to the uncertainty of measurement under consideration, so that the measurand can be represented by an essentially unique value. The IEC scenario focuses on measurements with single readings, permitting the investigation of whether quantities vary in time by demonstrating whether measurement results are compatible. The IEC views also allow non-negligible definitional uncertainties. The validity of the measurement results is highly dependent on the metrological properties of the instrument as determined by its calibration.

III. Uncertainty of measurement and uncertainty or error of measuring instruments

The uncertainty of the result of a measurement reflects the lack of exact knowledge of the value of the measurand.
In Table 1 the comparison VIM [3], VIM Draft [4] and IEC standards [5–7] terms concerning uncertainty of measurement are driven.

TABLE I. VIM Draft and IEC standards terms comparison

VIM Draft terms	IEC standards terms
• *Measurement uncertainty*: parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used (VIM Draft, 2.27 [4] – VIM-1993, 3.9 [3]). Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the *definitional* uncertainty.	*Measurement uncertainty*: • parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used (IEC 60359, 3.1.4) [5]; • maximum expected deviation of a measured value from its actual value (IEC 61000-4-30, 3.17) [6]. The parameter can be, for example, a standard deviation (or a given multiple of it), or a half-width of an interval having a stated level of confidence (IEC 60359, 3.1.4).
• *Definitional uncertainty*: minimum measurement uncertainty resulting from the inherently finite amount of detail in the definition of a measurand (VIM Draft, 2.28) [4]. Any change in the descriptive detail of a measurand requires another model leading to another measurand having another definitional uncertainty.	*Intrinsic uncertainty*: • minimum uncertainty that can be assigned in the description of a measured quantity (IEC 60359, 3.1.11) [5]; • uncertainty of a measuring instrument when used under reference condition (IEC 61557-12, 2.2.2) [7]. In this case, it is a percentage of the measured value defined in its rated and with the other influence quantities under reference conditions, unless otherwise stated (IEC 61557-12, 2.2.2). The uncertainty is an intrinsic part of any result of measurement, i.e. that a value is meaningless if it is not accompanied by its uncertainty, is that the operating conditions shall be specified by ranges, not by single values.
-	*Intrinsic instrumental uncertainty*: uncertainty of a measuring instrument when used under reference conditions (IEC 60359, 3.2.10) [5].

VIM Draft terms	IEC standards terms
	Absolute instrumental uncertainty: uncertainty of the result of a direct measurement of a measurand having negligible intrinsic uncertainty (IEC 60359, 3.1.12) [5].
	Operating uncertainty: uncertainty under the rated operating conditions (IEC 61557-12, 2.2.6) [7].
	Operating instrumental uncertainty: instrumental uncertainty under the rated operating conditions (IEC 60359, 3.2.11) [5].
	Limit of uncertainty: limiting value of the instrumental uncertainty for equipment operating under specified conditions (IEC 60359, 3.3.6) [5].

International standard IEC 60359 is based on the methods expounded in GUM for expressing and evaluating the uncertainty of measurement, and refers to GUM for the statistical procedures to be used in determining the intervals assigned to represent uncertainty. This standard does not address the propagation of uncertainty beyond the measuring instrument or equipment whose performance is considered and which may undergo compliance testing. The object is to provide methods for ensuring uniformity in the specification and determination of uncertainties of equipment within its scope [5].

In the GUM, D.3.4 [1], and in IEC 60359 [5] the concept "definitional uncertainty" is termed "intrinsic uncertainty", but these terms have different definitions and have concern to different objects. Any change in the descriptive detail of a measurand requires another model leading to another measurand having another definitional uncertainty (VIM Draft) [4]. Alongside the conceptual and terminological evolution from "error" to "uncertainty", the standards on the performance of electrical measuring instruments underwent also an evolution in scope. At first standards were published on electrical indicating instruments, where the concepts of "intrinsic error" and variations were developed. Then standards on electronic measurement instruments followed. A definitional uncertainty therefore sets a minimum limit to any measurement uncertainty. The uncertainty is an intrinsic part of any result of measurement. The result of a measurement carried out with the *intrinsic* uncertainty of the measurand may be called the best measurement of the quantity in question (IEC 60359, 3.1.11).

Unless explicitly stated otherwise, the *instrumental* uncertainty is expressed as an interval with coverage factor 2 (IEC 60359, 3.1.12). In single-reading direct measurements of measurands having intrinsic uncertainty small with respect to the instrumental uncertainty, the uncertainty of the measurement coincides, by definition, with the instrumental uncertainty. Otherwise the instrumental uncertainty is to be treated as a component of Type B in estimating the uncertainty of the measurement on the basis of the model connecting the several direct measurements involved.

The *operating instrumental* uncertainty, like the intrinsic one, is not evaluated by the user of the instrument, but is stated by its manufacturer or calibrator (IEC 60359, 3.2.11). The statement may be expressed by means of an algebraic relation involving the intrinsic instrumental uncertainty and the values of one or several influence quantities, but such a relation is just a convenient means of expressing a set of operating instrumental uncertainties under different operating conditions, not a functional relation to be used for evaluating the propagation of uncertainty inside the instrument.

A *limit of uncertainty* may be assigned by the manufacturer of the instrument, who states that under the specified conditions the *instrumental* uncertainty is never higher than this limit, or may be defined by standards, that prescribe that under specified conditions the instrumental uncertainty should not be larger than this limit for the instrument to belong to a given accuracy class. A limit of uncertainty may be expressed in absolute terms or in the relative or fiducial forms (IEC 60359, 3.3.6) [5].

Instrumental uncertainty component of measurement is uncertainty arising from the measuring instrument or measuring system in use, and obtained by its calibration (VIM Draft, 4.23) [4]. The instrumental uncertainty is used in a Type B evaluation of measurement uncertainty. Information relevant to instrumental uncertainty may be given in the instrument specifications. All the information on the instrumental uncertainty, i.e. the uncertainty of direct measurements by calibrated instruments, is conveyed conceptually by a calibration diagram. The calibration diagram does not need to be presented in a graphical

format: in most cases tables or algebraic relations are more convenient (IEC 60359) [5].
Measurement error is difference of measured quantity value and reference quantity value (VIM Draft, 2.17–3.10). The error concept can be used when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a measurement standard of negligible measurement uncertainty or if a conventional quantity value is given, or if the measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range. Measurement error should not be confused with production error or mistake (VIM Draft, 2.27) [4].
The operation *error* (B) as in IEC 60359, 4.1 [5] and *uncertainty* (B) as in IEC 61557-12 [7] will be calculated by means of the following equation as shown in Table 2 and this procedure is incorrect.

TABLE 2. Incorrect method application GUM in draft of international standards

IEC 60359, 4.1	**IEC 61557-12**
$B = \pm(\lvert A \rvert + 1.15\sqrt{E_i^2})$	
where: A is the intrinsic ***error***; E_i is the variation; *i* is the consecutive number of the variation.	where: A is the intrinsic ***uncertainty***; E_i is the variation; *i* is the consecutive number of the variation.

Simplified estimation of expanded measurement uncertainty for Type A is shown on Fig. 1.

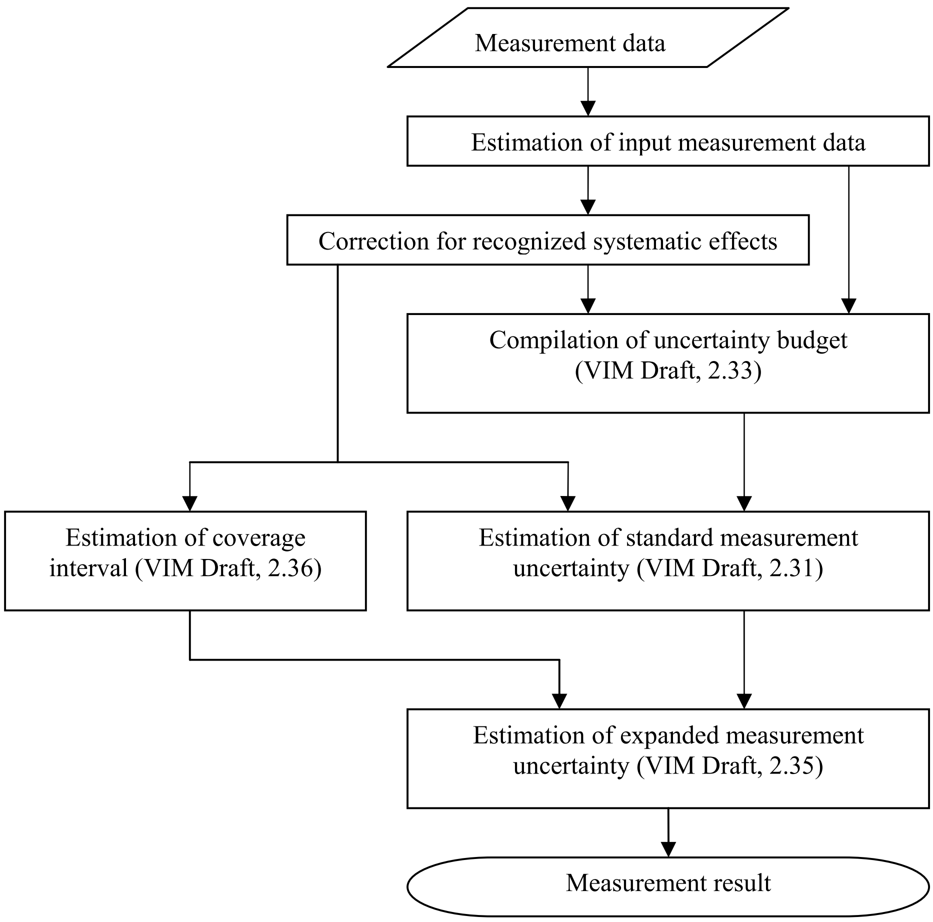

Fig. 1. Simplified estimation of expanded measurement uncertainty (Type A)

In GUM the overall standard uncertainty u_c arising from the combination of uncertainties components calculated using equation [1]:

$$u_c = \sqrt{\sum_{i=1}^{m} u_i^2}\ , \tag{1}$$

where:
u_i is the components of uncertainty.
Estimation of the standard measurement uncertainty u_A (x_i) of measurement i-th input values without correlation input values may be calculated by means of the following equation:

$$u_A(x_i) = \sqrt{\frac{1}{n_i(n_i-1)}\sum_{q=1}^{n_i}\left(x_{iq}-\bar{x}_i\right)^2}\ , \tag{2}$$

$$\bar{x}_i = \frac{1}{n}\sum_{q=1}^{n_i} x_{iq} \tag{3}$$

where:
x_{iq} is the measurement results of i-th input values;
$\bar{x}_i$ is the arithmetic median of measurement results of i-th input values.
Estimation of the expanded measurement uncertainty U_p may be calculated by means of the following equation:

$$U_p = k \cdot u_c\,. \tag{4}$$

where:
U_p is the expanded measurement uncertainty;
k is the coverage factor (typically k=2).
Correct GUM procedure of estimation of the expanded measurement uncertainty may be with using of equations (1) – (4) and using specified of coverage factor. Moreover, the symbol "±" should be avoided whenever possible because it has traditionally been used to indicate an interval corresponding with expanded uncertainty (GUM, 7.2.2).

IV. Conclusions

In documents and recommendations international and regional organizations in field of metrology, standardization and the accreditation of laboratories thesis of GUM widely are used. Thesis of international GUM is also widely used in national standards and other normative documents. Carried out analysis incorrect the use of thesis of GUM in some international standards is shown. Recommendations as to correct the use of thesis of GUM at the development of the draft of international standards are executed. Simple replacement term "error" on "uncertainty" in draft of international standards is not true procedure.

References

[1] Guide to the Expression of Uncertainty in Measurement (GUM). – First edition. – *ISO*. – Switzerland. – 1995. – 101 p.
[2] *OIML D 16* Edition 1986 (E). Principles of assurance of metrological control.
[3] International Vocabulary of Basic and General Terms in Metrology (VIM). – Second edition. – *ISO*. – Switzerland. –, 1993. – 59 p.
[4] ISO VIM (DGUIDE 99999.2) International Vocabulary of Basic and General Terms in Metrology (VIM Draft). – Third edition. – *ISO*. – Switzerland, 2006. – 145 p.
[5] *IEC 60359:2001* Electrical and electronic measurement equipment. – Expression of performance.
[6] *IEC 61000-4-30:2003* Electromagnetic capability (EMC). – Part 4-30: Testing and measurement techniques. Power quality measurement method.
[7] *IEC 61557-12:2007* Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures. – Part 12: Combined performance measuring and monitoring devices for electrical parameters.