BRITISH STANDARD

BS EN 60359:2002
IEC 60359:2001

Electrical and electronic measurement equipment — Expression of performance

The European Standard EN 60359:2002 has the status of a British Standard

ICS 17.220.20

National foreword

This British Standard is the official English language version of EN 60359:2002. It is identical with IEC 60359:2001. It supersedes BS 4889:1990 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/85, Measuring equipment for electrical and electromagnetic quantities, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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From 1 January 1997, all IEC publications have the number 60000 added to the old number. For instance, IEC 27-1 has been renumbered as IEC 60027-1. For a period of time during the change over from one numbering system to the other, publications may contain identifiers from both systems.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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English version

Electrical and electronic measurement equipment - Expression of performance
(IEC 60359:2001)

Appareils de mesure électriques et électroniques - Expression des performances (CEI 60359:2001)	Elektrische und elektronische Messeinrichtungen - Angabe zum Betriebsverhalten (IEC 60359:2001)

This European Standard was approved by CENELEC on 2002-03-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC
European Committee for Electrotechnical Standardization
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Foreword

The text of document 85/219/FDIS, future edition 3 of IEC 60359, prepared by IEC TC 85, Measuring equipment for electrical and electromagnetic quantities, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60359 on 2002-03-01.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2002-12-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2005-03-01

Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annex ZA is normative and annexes A and B are informative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60359:2001 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60051 (Series)	NOTE	Harmonized as EN 60051 (Series) (not modified).
IEC 60068 (Series)	NOTE	Harmonized as EN 60068 (Series) (not modified).
IEC 60529	NOTE	Harmonized as EN 60529:1991 (not modified).
IEC 60654 (Series)	NOTE	Harmonized as EN 60654 (Series) (not modified).
IEC 60721-3-0	NOTE	Harmonized as HD 478.3.0 S1:1987 (not modified).
IEC 60851-5	NOTE	Harmonized as EN 60851-5:1996 (not modified).

CONTENTS

INTRODUCTION

With the appearance of the interorganizational *Guide to the expression of uncertainty in measurement* (GUM) that embodied the suggestions of CIPM[1] Recommendation CI-1981, it became clear that the classical approach to the precision and accuracy of measurement in terms of true value and error is being superseded by the approach in terms of uncertainty. The intrinsic pitfalls of the concept of true value (hence of error) had indeed led the operative measurement world to rely increasingly on the concept of uncertainty, notwithstanding that the main body of standards concerning the performance of measuring instruments was still written in terms of the traditional approach. The widening gap between the best practice in metrology and the wording of the standards prompted the normative organizations to invite their Technical Committees to update these publications.

This new edition of the International Standard IEC 60359 was prepared in order to bring it into agreement with the GUM. During the procedure for its approval the chapters on measurement of the new edition of the International Electrotechnical Vocabulary (IEV) were published, and the opportunity was taken to bring the standard into agreement with the terms used in the IEV.

The main performance characteristics of an instrument are those related to the uncertainty of the results obtained by using the instrument. The GUM provides a general terminology and a computational framework for combining uncertainties of different origin, but it substantially deals with the issue of evaluating uncertainty in the measurement of a quantity defined as a function of other measured quantities, and does not address the issue of evaluating instrumental uncertainty, i.e. the uncertainty of the results of the single direct measurements carried out by the instruments. The GUM treats it as a component of uncertainty of category B, known from information supplied by the manufacturer or calibrator of the instrument, in the form of an expanded uncertainty with a stated coverage factor. It is therefore up to this standard to provide indications for expressing and evaluating instrumental uncertainty in a way consistent with the philosophy of the GUM. This means stating the requirements on performance of the instruments in terms of limits of uncertainty instead of limits of error, which implies a careful distinction between the indication of the instrument and the set of values assigned to describe the measurand (see Annex A for the conceptual evolution from the notion of error to the notion of uncertainty).

To this purpose, this standard systematically uses (in agreement with the IEV) the notion of calibration diagram, which is also quite helpful in describing the interplay between intrinsic uncertainty, variations, and operating uncertainty. Distinctions of this kind are essential, by the way, for the new measuring systems, based on microprocessors with internal software or using more than one input (multisensorial systems), that need to address the issue in general terms without restrictive hypotheses on the instrumental hardware. They also allow a wider choice of options in specifying performance characteristics.

For many people, of course, the passage from time-honored traditional terms and notions to the ones evolved by modern metrology will require some mental adjustment, which is altogether necessary, as current instrumentation has made giant steps from the times of index-on-scale instruments. However, no particular difficulty is expected in translating into terms consistent with this standard the bulk of existing technical specifications, most of which are written in terms of "limits of error", often with ambiguities about whether or not suggested corrections for influence quantities are included. When such ambiguities are removed, the old specifications are easily harmonized to this standard by substituting the "limits of error" with the "limits of instrumental uncertainty" expounded in clause 5, provided the contextual indications (if any) on the means of evaluating these limits are adjusted to satisfy the definitions given in this standard.

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[1] Comité International des Poids et Mesures (CIPM)

ELECTRICAL AND ELECTRONIC MEASUREMENT EQUIPMENT — EXPRESSION OF PERFORMANCE

1 Scope and object

This International Standard applies to the specification of performance, with primary reference to industrial applications, of the following kinds of electrical and electronic equipment:

- indicating and recording instruments which measure electrical quantities;
- material measures which supply electrical quantities;
- instruments which measure non-electrical quantities using electrical means, for all parts of the measuring chain which present electrical output signals.

This standard applies to the specification of performance of instruments operating in steady-state conditions (see 3.1.15), usual in industrial applications.

It 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 (including the way to account for non-negligible uncertainties in the traceability chain).

This standard does not address the propagation of uncertainty beyond the instrument (or the measuring 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. All other necessary requirements have been reserved for dependent IEC product standards pertaining to particular types of equipment which fall within the scope of this standard.

For example: the selection of metrological characteristics and their ranges, and of influence quantities and their specified operating ranges, is reserved for IEC product standards.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-300:2001, *International Electrotechnical Vocabulary (IEV) – Electrical and electronic measurements and measuring instruments – Part 311: General terms relating to measurements – Part 312: General terms relating to electrical measurements – Part 313: Types of electrical measuring instrument – Part 314: Specific terms according to the type of instrument*

ISO/IEC GUIDE EXPRES:1995, *Guide to the Expression of Uncertainty in Measurement*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

A word between brackets in the title of a definition is a qualifier that may be skipped if there is no danger of confusion with a similar term. When two terms may be used interchangeably with the same definition, these are separated by "or". Terms in italics in a note are new terms defined by the context.

Most definitions are taken or adapted, together with their notes, from Part 311 of IEC 60050-300 (International Electrotechnical Vocabulary – IEV). As only terms pertaining to the "uncertainty approach" are used, IEV notes stating that the term is used in this approach were omitted. Where such definitions are simultaneously drawn from the International Vocabulary of Basic and General Terms in Metrology (VIM), this has been indicated. In some cases, notes have been added for the purposes of this standard.

3.1 Basic definitions

3.1.1
measurand

quantity subjected to measurement, evaluated in the state assumed by the measured system during the measurement itself

NOTE 1 The value assumed by a quantity subjected to measurement when it is not interacting with the measuring instrument may be called *unperturbed value* of the quantity.

NOTE 2 The unperturbed value and its associated uncertainty can only be computed through a model of the measured system and of the measurement interaction with the knowledge of the appropriate metrological characteristics of the instrument, that may be called *instrumental load*.

3.1.2
(result of a) measurement

set of values attributed to a measurand, including a value, the corresponding uncertainty and the unit of measurement
[IEV 311-01-01, modified]

NOTE 1 The mid-value of the interval is called the value (see 3.1.3) of the measurand and its half-width the uncertainty (see 3.1.4) [IEV modified].

NOTE 2 The measurement is related to the indication (see 3.1.5) given by the instrument and to the values of correction obtained by calibration [IEV modified].

NOTE 3 The interval can be considered as representing the measurand provided that it is compatible with all other measurements of the same measurand [IEV modified].

NOTE 4 The width of the interval, and hence the uncertainty, can only be given with a stated level of confidence (see 3.1.4, NOTE 1) [IEV modified].

3.1.3
(measure-) value

mid element of the set assigned to represent the measurand

NOTE The measure-value is no more representative of the measurand than any other element of the set. It is singled out merely for the convenience of expressing the set in the format $V \pm U$, where V is the mid element and U the half-width of the set, rather than by its extremes. The qualifier "measure-" is used when deemed necessary to avoid confusion with the reading-value or the indicated value.

3.1.4
uncertainty (of measurement)

parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand
[IEV 311-01-02, VIM 3.9]

NOTE 1 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 [IEV, VIM].

NOTE 2 Uncertainty of measurement comprises, in general, many components. Some of these components can be evaluated from the statistical distribution of the results of a series of measurements and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated from the assumed probability distributions based on experience or other information [IEV, VIM].

NOTE 3 It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion [IEV, VIM].

NOTE 4 The definition and notes 1 and 2 are from GUM, clause B.2.18. The option used in this standard is to express the uncertainty as the half-width of an interval with the GUM procedures with a coverage factor of 2. This choice corresponds to the practice now adopted by many national standards laboratories. With the normal distribution a coverage factor of 2 corresponds to a level of confidence of 95 %. Otherwise statistical elaborations are necessary to establish the correspondence between the coverage factor and the level of confidence. As the data for such elaborations are not always available, it is deemed preferable to state the coverage factor. This interval can be "reasonably" assigned to describe the measurand, in the sense of the GUM definition, as in most usual cases it ensures compatibility with all other results of measurements of the same measurand assigned in the same way at a sufficiently high confidence level.

NOTE 5 Following CIPM document INC-1 and GUM, the components of uncertainty that are evaluated by statistical methods are referred to as *components of category A,* and those evaluated with the help of other methods as *components of category B.*

3.1.5
indication or reading-value

output signal of the instrument
[IEV 311-01-07, modified]

NOTE 1 The indicated value can be derived from the indication by means of the calibration curve [IEV].

NOTE 2 For a material measure, the indication is its nominal or stated value [IEV].

NOTE 3 The indication depends on the output format of the instrument:

- for *analogue outputs* it is a number tied to the appropriate unit of the display;
- for *digital outputs* it is the displayed digitized number;
- for *code outputs* it is the identification of the code pattern.

NOTE 4 For analogue outputs meant to be read by a human observer (as in the index-on-scale instruments) the unit of output is the unit of scale numbering; for analogue outputs meant to be read by another instrument (as in calibrated transducers) the unit of output is the unit of measurement of the quantity supporting the output signal.

3.1.6
calibration

set of operations which establishes the relationship which exists, under specified conditions, between the indication and the result of a measurement by reference to standards
[IEV 311-01-09]

NOTE 1 The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram [IEV].

NOTE 2 The calibration must be performed under well defined operating conditions for the instrument. The calibration diagram representing its result is not valid if the instrument is operated under conditions outside the range used for the calibration.

NOTE 3 Quite often, specially for instruments whose metrological characteristics are sufficiently known from past experience, it is convenient to predefine a simplified calibration diagram and perform only a verification of calibration (see 3.2.12) to check whether the response of the instrument stays within its limits. The simplified diagram is of course wider than the diagram that would be defined by the full calibration of the instrument, and the uncertainty assigned to the results of measurements is consequently larger.

3.1.7
calibration diagram

portion of the co-ordinate plane, defined by the axis of indication and the axis of results of measurement, which represents the response of the instrument to differing values of the measurand
[IEV 311-01-10]

3.1.8
calibration curve

curve which gives the relationship between the indication and the value of the measurand
[IEV 311-01-11]

NOTE 1 The calibration curve is the curve bisecting the width of the calibration diagram parallel to the axis of results of measurement, thus joining the points representing the values of the measurand (see 6.1 and Figure 1).

NOTE 2 When the calibration curve is a straight line passing through zero, it is convenient to refer to the slope which is known as the instrument constant [IEV].

3.1.9
indicated value

value given by an indicating instrument on the basis of its calibration curve
[IEV 311-01-08]

NOTE The indicated value is the measure-value of the measurand when the instrument is used in a direct measurement (see 3.2.7) under all the operating conditions for which the calibration diagram is valid.

3.1.10
(measurement) compatibility

property satisfied by all the results of measurement of the same measurand, characterized by an adequate overlap of their intervals
[IEV 311-01-14]

NOTE 1 The compatibility of any result of a measurement with all the other ones that represent the same measurand can be asserted only at some level of confidence, as it depends on statistical inference, a level that should be indicated, at least by implicit convention or through a coverage factor.

NOTE 2 The compatibility of the results of measurements obtained with different instruments and methods is ensured by the traceability (see 3.1.16) to a common primary standard (see 3.2.6) of the standards used for the calibration of the several instruments (and of course by the correctness of the calibration and operation procedures).

NOTE 3 When two results of a measurement are not compatible one must decide by independent means whether one or both results are wrong (perhaps because the uncertainty is too narrow), or whether the measurand is not the same.

NOTE 4 Measurements carried out with wider uncertainty yield results which are compatible on a wider range, because they discriminate less among different measurands allowing to classify them with simpler models; with narrower uncertainties the compatibility calls for more detailed models of the measured systems.

3.1.11
intrinsic uncertainty of the measurand

minimum uncertainty that can be assigned in the description of a measured quantity

NOTE 1 No quantity can be measured with narrower and narrower uncertainty, inasmuch as any given quantity is defined or identified at a given level of detail. If one tries to measure a given quantity with uncertainty lower than its own intrinsic uncertainty one is compelled to redefine it with higher detail, so that one is actually measuring another quantity. See also GUM D.1.1.

NOTE 2 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.

3.1.12
(absolute) instrumental uncertainty

uncertainty of the result of a direct measurement of a measurand having negligible intrinsic uncertainty

NOTE 1 Unless explicitly stated otherwise, the instrumental uncertainty is expressed as an interval with coverage factor 2.

NOTE 2 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 category B in evaluating the uncertainty of the measurement on the basis of the model connecting the several direct measurements involved.

NOTE 3 The instrumental uncertainty automatically includes, by definition, the effects due to the quantization of the reading-values (minimum evaluable fraction of the scale interval in analogic outputs, unit of the last stable digit in digital outputs).

NOTE 4 For material measures the instrumental uncertainty is the uncertainty that should be associated to the value of the quantity reproduced by the material measure in order to ensure the compatibility of the results of its measurements.

NOTE 5 When possible and convenient the uncertainty may be expressed in the relative form (see 3.3.3) or in the fiducial form (see 3.3.4). The *relative uncertainty* is the ratio U/V of the absolute uncertainty U to the measure value V, and the *fiducial uncertainty* the ratio U/V_f of the absolute uncertainty U to a conventionally chosen value V_f.

3.1.13
conventional value

measure-value of a standard used in a calibration operation and known with uncertainty negligible with respect to the uncertainty of the instrument to be calibrated

NOTE This definition is adapted to the object of this standard from the definition of "conventional true value (of a quantity)": value attributed to a particular quantity and accepted, sometimes by convention, as having an uncertainty appropriate for a given purpose [IEV 311-01-06, VIM 1.20]

3.1.14
influence quantity

quantity which is not the subject of the measurement and whose change affects the relationship between the indication and the result of the measurement
[IEV 311-06-01]

NOTE 1 Influence quantities can originate from the measured system, the measuring equipment or the environment [IEV].

NOTE 2 As the calibration diagram depends on the influence quantities, in order to assign the result of a measurement it is necessary to know whether the relevant influence quantities lie within the specified range [IEV].

NOTE 3 An influence quantity is said to lie within a range C' to C'' when the results of its measurement satisfy the relationship: $C' \leq V - U < V + U \leq C''$.

3.1.15
steady-state conditions

operating conditions of a measuring device in which the variation of the measurand with the time is such that the relation between the input and output signals of the instruments does not suffer a significant change with respect to the relation obtaining when the measurand is constant in time

3.1.16
traceability

property of the result of a measurement or of the value of a standard such that it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties
[IEV 311-01-15, VIM 6.10]

NOTE 1 The concept is often expressed by the adjective traceable [IEV, VIM].

NOTE 2 The unbroken chain of comparisons is called a traceability chain [IEV, VIM].

NOTE 3 The traceability implies that a metrological organization be established with a hierarchy of standards (instruments and material measures) of increasing intrinsic uncertainty. The chain of comparisons from the primary standard to the calibrated device adds indeed new uncertainty at each step.

NOTE 4 Traceability is ensured only within a given uncertainty, that should be specified.

3.2 Definitions of devices and operations

3.2.1
(measuring) instrument

device intended to be used to make measurements, alone or in conjunction with supplementary devices
[IEV 311-03-01, VIM 4.1]

NOTE The term "(measuring) instruments" includes both the indicating instruments and the material measures.

3.2.2
indicating (measuring) instrument

measuring instrument which displays an indication
[IEV 311-03-02, VIM 4.6]

NOTE 1 The display can be analogue (continuous or discontinuous), digital or coded [IEV].

NOTE 2 Values of more than one quantity can be displayed simultaneously [IEV].

NOTE 3 A displaying measuring instrument can also provide a record [IEV].

NOTE 4 The display can consist of an output signal not directly readable by a human observer, but able to be interpreted by suitable devices [IEV].

NOTE 5 An indicating instrument may consist of a chain of transducers with the possible addition of other process devices, or it may consist of one transducer.

NOTE 6 The interaction between the indicating instrument, the measured system and the environment generates a signal in the first stage of the instrument (called *sensor*). This signal is elaborated inside the instrument into an *output signal* which carries the information on the measurand. The description of the output signal in a suitable output format is the indication supplied by the instrument.

NOTE 7 A chain of instruments is treated as a single indicating instrument when a single calibration diagram is available that connects the measurand to the output of the last element of the chain. In this case the influence quantities must be defined for the whole chain.

3.2.3
material measure

device intended to reproduce or supply, in a permanent manner during its use, one or more known values of a given quantity
[IEV 311-03-03, VIM 4.2]

NOTE 1 The quantity concerned may be called the *supplied quantity* [IEV].

NOTE 2 The definition covers also those devices, such as signal generators and standard voltage or current generators, often referred to as *supply instruments***.**

NOTE 3 The identification of the value and uncertainty of the supplied quantity is given by a number tied to a unit of measurement or a code term, called the *nominal value* or *marked value* of the material measure.

3.2.4
electrical measuring instrument

measuring instrument intended to measure an electrical or non-electrical quantity using electrical or electronic means
[IEV 311-03-04]

3.2.5
transducer

technical device which performs a given elaboration on an input signal, transforming it into an output signal

NOTE All indicating instruments contain transducers and they may consist of one transducer. When the signals are elaborated by a chain of transducers, the input and output signals of each transducer are not always directly and univocally accessible.

3.2.6
primary standard

standard that is designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity
[IEV 311-04-02, VIM 6.4]

NOTE 1 The concept of a primary standard is equally valid for base quantities and derived quantities [IEV].

NOTE 2 A primary standard is never used directly for measurement other than for comparison with duplicate standards or reference standards [IEV].

3.2.7
direct (method of) measurement

method of measurement in which the value of a measurand is obtained directly, without the necessity for supplementary calculations based on a functional relationship between the measurand and other quantities actually measured
[IEV 311-02-01]

NOTE 1 The value of the measurand is considered to be obtained directly even when the scale of a measuring instrument has values which are linked to corresponding values of the measurand by means of a table or a graph [IEV].

NOTE 2 The method of measurement remains direct even if it is necessary to make supplementary measurements to determine the values of influence quantities in order to make corrections [IEV].

NOTE 3 The definitions of the metrological characteristics of the instruments refer implicitly to their use in direct measurements.

3.2.8
indirect (method of) measurement

method of measurement in which the value of a quantity is obtained from measurements made by direct methods of measurement of other quantities linked to the measurand by a known relationship
[IEV 311-02-02]

NOTE 1 In order to apply an indirect method of measurement one needs a model able to supply the relationship, fully explicitated, between the measurand and the parameters that are measured by direct measurement.

NOTE 2 The computations must be carried out on both values and uncertainties, and therefore require accepted rules for the propagation of the uncertainty as provided by the GUM.

3.2.9
(method of) measurement by repeated observations

method of measurement by which the result of the measurement is assigned on the basis of a statistical analysis on the distribution of the data obtained by several observations repeated under nominally equal conditions

NOTE 1 One should resort to a statistical analysis when the instrumental uncertainty is too small to ensure the measurement compatibility. This may happen in two quite different sets of circumstances:

a) when the measurand is a quantity subjected to intrinsic statistical fluctuations (e.g. in measurements involving nuclear decay). In this case the actual measurand is the statistical distribution of the states of the measured quantity, to be described by its statistical parameters (mean and standard deviation). The statistical analysis is carried out on a population of results of measurement, each with its own value and uncertainty, as each observation correctly describes one particular state of the measured quantity. The situation may be considered a particular case of indirect measurement.

b) when the noise associated with the transmission of signals affects the reading-value more than in the operating conditions used for the calibration, contributing to the uncertainty of the measurement to an extent comparable with the instrumental uncertainty or higher (e.g. in the field use of surveyor instruments). In this case the statistical analysis is carried out on a population of reading-values with the purpose of separating the information on the measurand from the noise. The situation may be considered as a new calibration of the instrument for a set of operating conditions outside their rated range.

NOTE 2 One cannot presume to obtain by means of repeated observation an uncertainty lower than the instrumental uncertainty assigned by the calibration or the class of precision of the instrument. Indeed if the results of the repeated measurements are compatible with each other within the instrumental uncertainty, the latter is the valid datum for the uncertainty of the measurement and several observations do not bring more information than one; if on the other hand they are not compatible within the instrumental uncertainty, the final result of the measurement should be expressed with a larger uncertainty in order to make all results compatible as they should be by definition.

NOTE 3 For instruments that exhibit non-negligible hysteresis a straightforward statistical analysis of repeated observations is misleading. Appropriate test procedures for such instruments should be expounded in their particular standards.

3.2.10
intrinsic (instrumental) uncertainty

uncertainty of a measuring instrument when used under reference conditions
[IEV 311-03-09]

3.2.11
operating instrumental uncertainty

instrumental uncertainty under the rated operating conditions

NOTE 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. 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.

3.2.12
verification (of calibration)

set of operations which is used to check whether the indications, under specified conditions, correspond with a given set of known measurands within the limits of a predetermined calibration diagram
[IEV 311-01-13]

NOTE 1 The known uncertainty of the measurand used for verification will generally be negligible with respect to the uncertainty assigned to the instrument in the calibration diagram [IEV].

NOTE 2 The verification of calibration of a material measure consists in checking whether the result of a measurement of the supplied quantity is compatible with the interval given by the calibration diagram.

3.2.13
adjustment (of a measuring instrument)

set of operations carried out on an instrument in order that it provides given indications corresponding to given values of the measurand
[IEV 311-03-16]

NOTE When the instrument is made to give a null indication corresponding to a null value of the measurand, the set of operations is called *zero adjustment* [IEV].

3.2.14
user adjustment (of a measuring instrument)

adjustment, employing only the means at the disposal of the user, specified by the manufacturer
[IEV 311-03-17, VIM 4.31]

3.2.15
deviation (for the verification of calibration)

difference between the indication of an instrument undergoing verification of calibration and the indication of the reference instrument, under equivalent operating conditions
[IEV 311-01-20]

NOTE 1 The comparison of the indications may be carried out by simultaneous measurement or by substitution. In principle the comparison ought to be carried out on the same measurand in the same measuring conditions, but this is impossible because the measurand can never be rigorously the same. Only the metrological expertise of the operator can warranty that the difference in the measurement conditions of the two instruments is negligible for the comparison purposes.

NOTE 2 If one of the instruments is a material measure, its nominal value is taken as the assigned measure-value.

NOTE 3 The term is used only in operations of verification of calibration where the uncertainty of the reference instrument is negligible by definition.

3.3 Definitions on manners of expression

3.3.1
metrological characteristics

data concerning the relations between the readings of a measuring instrument and the measurements of the quantities interacting with it

3.3.2
range

domain of values of a quantity included between a lower and an upper limit

NOTE 1 The term "range" is usually used with a modifier. It may apply to a performance characteristic, to an influence quantity, etc.

NOTE 2 When one of the limits of a range is zero or infinity, the other finite limit is called a *threshold*.

NOTE 3 No uncertainty is associated with the values of range limits or thresholds as they are not themselves results of measurements but a priori statements about conditions to be met by results of measurements. If the result of a measurement has to lay within a rated range, it is understood that the whole interval $V \pm U$ representing it must lay within the values of the range limits or beyond the threshold value, unless otherwise specified by relevant standards or by explicit agreements.

NOTE 4 A range may be expressed by stating the values of its lower and upper limits, or by stating its mid value and its half-width.

3.3.3
relative form of expression

expression of a metrological characteristic, or of other data, by means of its ratio to the measure value of the quantity under consideration

NOTE 1 Expression in relative form is possible when the quantity under consideration allows the ratio relationship and its value is not zero.

NOTE 2 Uncertainties and limits of uncertainty are expressed in relative form by dividing their absolute value by the value of the measurand, ranges of influence quantities by dividing the halved range by the mid value of the domain, etc.

3.3.4
fiducial form of expression

expression of a metrological characteristic, or of other data, by means of its ratio to a conventionally chosen value of the quantity under consideration

NOTE 1 Expression in fiducial form is possible when the quantity under consideration allows the ratio relationship.

NOTE 2 The value to which reference is made in order to define the fiducial error is called *fiducial value*.

3.3.5
variation (due to an influence quantity)

difference between the indicated values for the same value of the measurand of an indicating instrument, or the values of a material measure, when an influence quantity assumes, successively, two different values
[IEV 311-07-03]

NOTE 1 The uncertainty associated with the different measure values of the influence quantity for which the variation is evaluated should not be wider than the width of the reference range for the same influence quantity. The other performance characteristics and the other influence quantities should stay within the ranges specified for the reference conditions.

NOTE 2 The variation is a meaningful parameter when it is greater than the intrinsic instrumental uncertainty.

3.3.6
limit of uncertainty

limiting value of the instrumental uncertainty for equipment operating under specified conditions

NOTE 1 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.

NOTE 2 A limit of uncertainty may be expressed in absolute terms or in the relative or fiducial forms.

3.3.7
accuracy class

class of measuring instruments, all of which are intended to comply with a set of specifications regarding uncertainty
[IEV 311-06-09]

NOTE 1 An accuracy class always specifies a limit of uncertainty (for a given range of influence quantities), whatever other metrological characteristics it specifies.

NOTE 2 An instrument may be assigned to different accuracy classes for different rated operating conditions.

NOTE 3 Unless otherwise specified, the limit of uncertainty defining an accuracy class is meant as an interval with coverage factor 2.

3.3.8
rated value

quantity value assigned by a manufacturer for a specified operating condition of the equipment or instrument

NOTE A rated value V assigned with an uncertainty U is actually a range $V \pm U$ and should be handled as such (see 3.3.2, note 4)

3.3.9
(specified) measuring range

range defined by two values of the measurand, or quantity to be supplied, within which the limits of uncertainty of the measuring instrument are specified
[IEV 311-03-12]

NOTE 1 An instrument can have several measuring ranges [IEV].

NOTE 2 The upper and lower limits of the specified measuring range are sometimes called the *maximum capacity* and *minimum capacity* respectively.

3.3.10
reference conditions

appropriate set of specified values and/or ranges of values of influence quantities under which the smallest permissible uncertainties of a measuring instrument are specified
[IEV 311-06-02, modified]

NOTE The ranges specified for the reference conditions, called *reference ranges*, are not wider, and are usually narrower, than the ranges specified for the rated operating conditions.

3.3.11
reference value

specified value of one of a set of reference conditions
[IEV 311-07-01, modified]

3.3.12
reference range

specified range of values of one of a set of reference conditions
[IEV 311-07-02, modified]

3.3.13
rated operating conditions

set of conditions that must be fulfilled during the measurement in order that a calibration diagram may be valid

NOTE Beside the specified measuring range and rated operating ranges for the influence quantities, the conditions may include specified ranges for other performance characteristics and other indications that cannot be expressed as ranges of quantities.

3.3.14
nominal range of use or rated operating range (for influence quantities)
specified range of values which an influence quantity can assume without causing a variation exceeding specified limits
[IEV 311-07-05]

NOTE The rated operating range of each influence quantity is a part of the rated operating conditions.

3.3.15
limiting conditions
extreme conditions which an operating measuring instrument can withstand without damage and without degradation of its metrological characteristics when it is subsequently operated under its rated operating conditions

3.3.16
limiting values for operation
extreme values which an influence quantity can assume during operation without damaging the instrument so that it no longer meets its performance requirements when it is subsequently operated under reference conditions
[IEV 311-07-06]

NOTE The limiting values can depend on the duration of their application [IEV].

3.3.17
storage and transport conditions
extreme conditions which a non-operating measuring instrument can withstand without damage and without degradation of its metrological characteristics when it is subsequently operated under its rated operating conditions

3.3.18
limiting values for storage
extreme values which an influence quantity can assume during storage without damaging the instrument so that it no longer meets its performance requirements when it is subsequently operated under reference conditions
[IEV 311-07-07]

NOTE The limiting values can depend on the duration of their application [IEV].

3.3.19
limiting values for transport
extreme values which an influence quantity can assume during transport without damaging the instrument so that it no longer meets its performance requirements when it is subsequently operated under reference conditions
[IEV 311-07-08]

NOTE The limiting values can depend on the duration of their application [IEV].

4 Specification of values and ranges

4.1 The manufacturer shall state rated values or specified ranges for all quantities which he considers to be metrological characteristics applicable to the particular equipment. The statements on values and ranges shall be accompanied by the appropriate statements on uncertainty.

4.2 The manufacturer shall state a reference range and/or a rated operating range for each influence quantity which he takes into account. The rated operating range shall include the whole of the reference range.

4.3 The manufacturer shall specify the limiting conditions and storage and transport conditions for each specified influence quantity. If no ranges are specified, the rated operating conditions are considered to be limiting conditions and to include the storage and transport conditions.

4.4 The uncertainty shall be expressed as the half-width of an interval with coverage factor 2 (see 3.1.4, notes 1 and 4).

5 Requirements for IEC standards related to the equipment

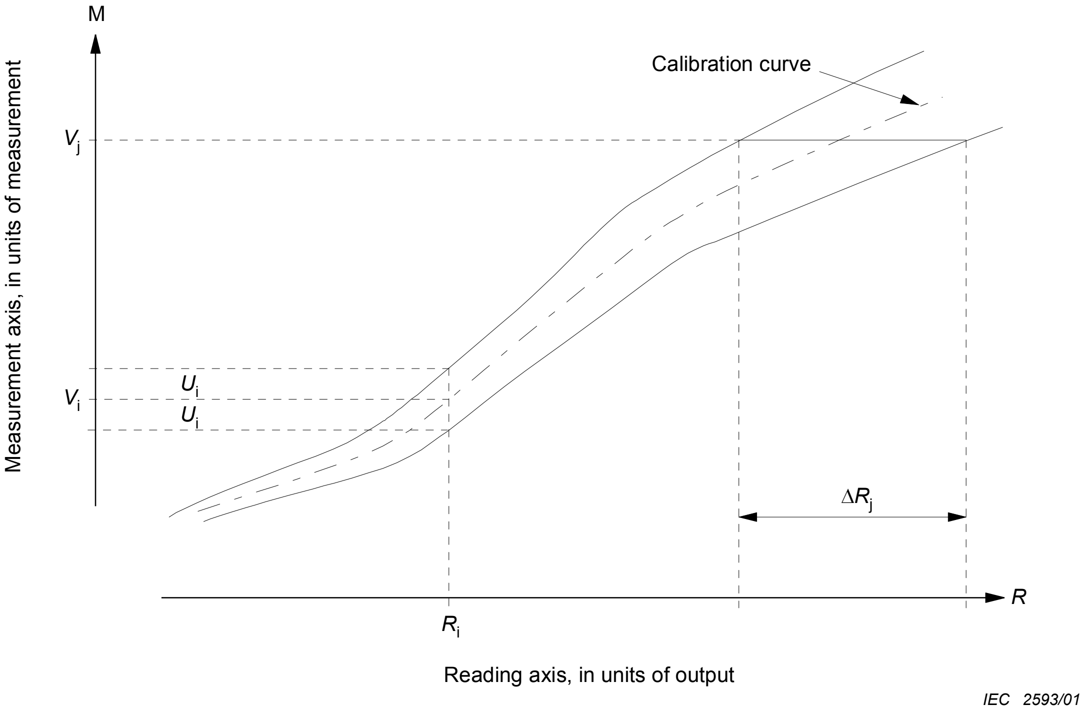
5.1 IEC standards covering all kinds of equipment falling within the scope of this standard shall observe the rules laid down herein, and especially the following points:

5.2 An IEC standard related to the equipment shall call for particular specifications to include the relevant metrological characteristics and influence quantities, as well as the type of information used in specifying limits of uncertainty. It should also include the limiting conditions and the storage and transport conditions.

5.3 An IEC standard related to the equipment shall not contradict any requirement of this standard.

6 Specification of limits of uncertainty

6.1 All the information on the instrumental uncertainty, i.e. the uncertainty of direct measurements by calibrated instruments, is conveyed conceptually by a calibration diagram (see 3.1.7), i.e. the portion of the coordinate plane defined by the axis R of the indications (in units of output) and the axis M of the values (in units of measurement) that represents the response of the instrument to measurands of different values (Figure 1). The calibration diagram does not need to be presented in a graphical format: in most cases tables or algebraic relations are more convenient, but the synthetic view offered by the graphical format is more suitable for general discussions.



M = axis of the measure-values, in units of measurement
R = axis of the indications, in units of output
V_j = value of known measurand j
ΔR_j = range of indications for known measurand j
R_i = indication for unknown measurand i
V_i = measure-value assigned to unknown measurand i
U_i = uncertainty of unknown measurand i

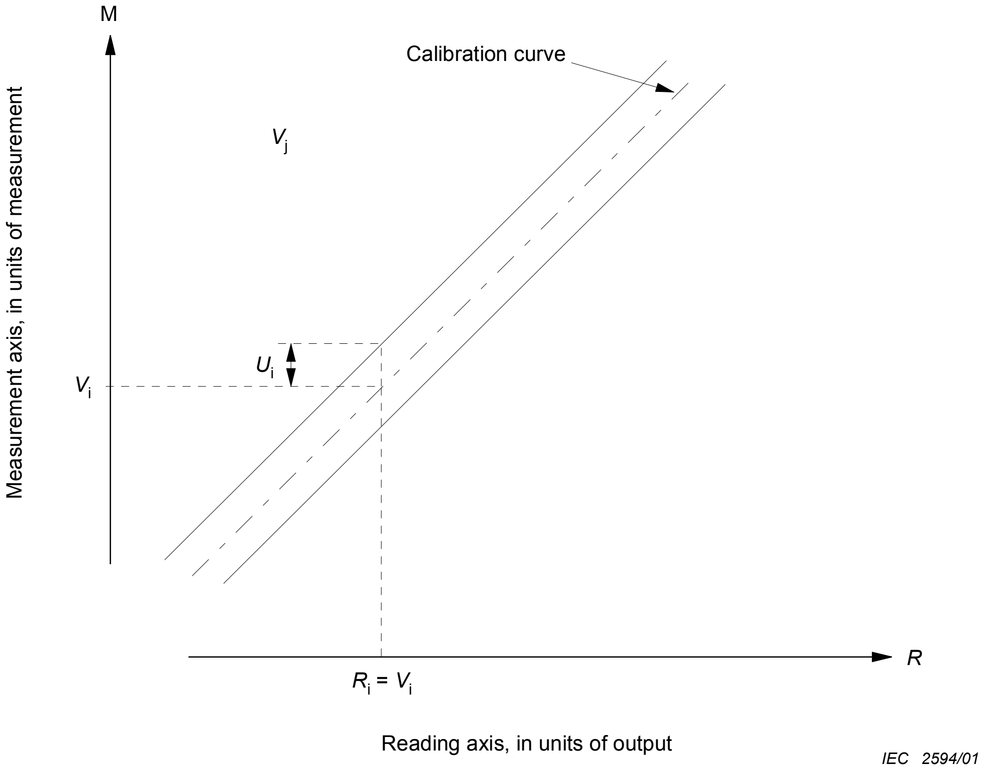
Figure 1 – Calibration diagram

In principle, the calibration diagram is built by determining the segments ΔR_j representing the range of reading-values that one can expect to obtain, at a given level of confidence, in measurements, carried out through the whole range of the specified operating conditions, of measurands of measure-values V_j, known with uncertainty much lower than that of the instrument, i.e. such that their values can be used as "conventional (true) values" (see 3.1.13). The segment $(V \pm U)_i$ intercepted on this diagram by the parallel to the M axis traced through the reading-value R_i obtained in a particular measurement yields the result of the measurement, because it is compatible with all of, and only with, the other results that can be obtained by measuring the same measurand. Compatibility is here evaluated with correlation coefficient $r = -1$ because the measurements at the limit of compatibility are carried out by definition at the opposite extremes of the combined effect of the operating conditions.

The calibration curve (see 3.1.8) is the curve joining the mid points of the segments intercepted by the calibration diagram on the parallels to the M axis. The absolute instrumental uncertainty is given by the half-length of the segment intercepted by the calibration diagram on parallels to the M axis (Figure 1). The measuring range (see 3.3.9) is the segment of the measurement axis for which the calibration curve is defined.
]

In most instruments designed for field use the output display is so arranged, by choosing a suitable unit of output, as to make the numbers expressing the indication coincide with those expressing the measure-value. This way the calibration curve is a straight line with unit slope, and the scale is marked directly in units of measurement for user convenience (Figure 2). This formal simplification does not alter the conceptual difference between the indication (reading-value) and the measure-value assigned as the result of a measurement: the calibration diagram is still used to determine the uncertainty.

For material measures which have only one nominal value, or a discrete set of nominal values, the calibration diagram is reduced to one segment parallel to the M axis, or a discrete set of such segments.



M = axis of the measure-values, in units of measurement

R = axis of the indications, in units of output

V_i = measure-value assigned to measurand i

R_i = V_i = indication for measurand i, made numerically equal to its measure-value

U_i = uncertainty of measurand i

Figure 2 – Calibration diagram with scale marks in units of measurement

6.2 In principle the specification of limits of uncertainty consists in assigning predefined calibration diagrams that the instrument is expected to meet under a verification of the calibration. Indeed, it is not matter of assessing the uncertainty of a particular measurement, nor even of assessing the instrumental uncertainty of a particular instrument, but of setting a limit to such an instrumental uncertainty: it is matter of defining a general calibration diagram wide enough to include the actual calibration diagrams of the instruments satisfying the specification, so that the uncertainty assigned in terms of this limit is not higher that the actual (but unknown) uncertainty.

The diagrams may be defined by algebraic expressions giving the calibration curve and the uncertainty as functions of the values in the specified measuring range. The operating conditions under which the diagrams are valid should be clearly specified.

For all equipment a basic calibration diagram is given in reference conditions, which determines the intrinsic instrumental uncertainty. The problem is how to evaluate the instrumental uncertainty in other and/or wider operating conditions.

In operating conditions different from the reference ones, the calibration diagram may be expected to change its width and/or to shift in the M-R plane (Figure 3). The variation (see 3.3.5) describes the shift of the calibration curve when one influence quantity assumes values outside the reference range, but does not tell anything about the width of the new calibration diagram, that in any case depends on the operating range of this influence quantity around its rated value.

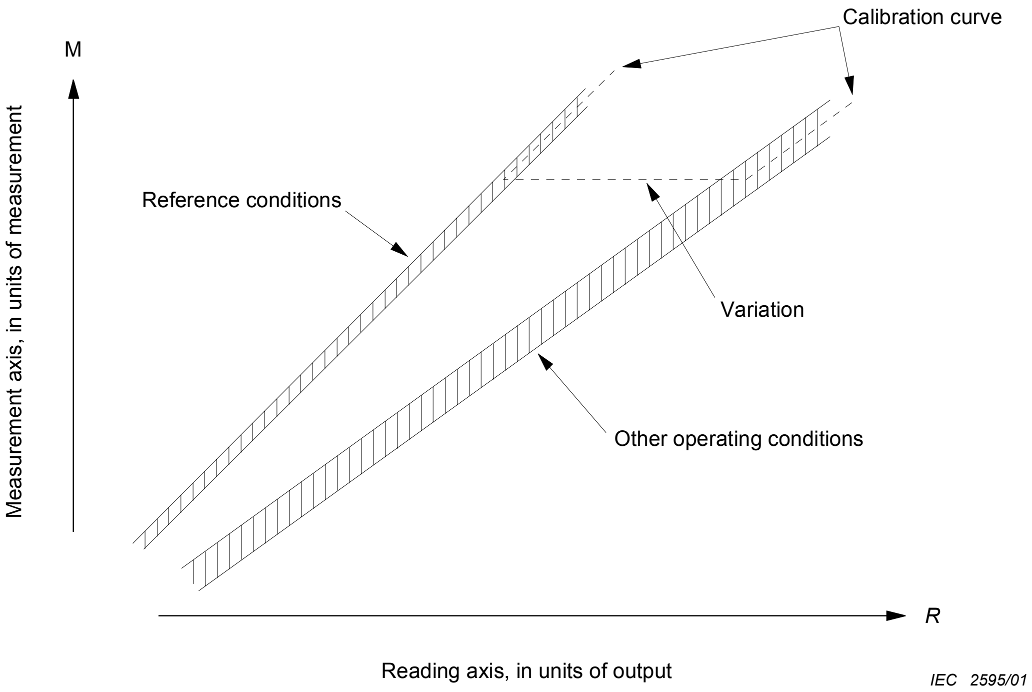
Operating conditions with one influence quantity outside the reference range may be specified in two ways:

a) a rated value, or a set of rated values, is given for the influence quantity, defined with a range approximately as wide as the reference range: the user is expected to know the value of the influence quantity within a given uncertainty;

b) a rated operating range is given for the influence quantity, that includes the reference range: the user is not expected to know the value of the influence quantity, but only to know that it lies within the range.

In case a) the calibration diagram may shift in the M-R plane as in Figure 3 giving rise to a new calibration curve. The variation may be used to determine this new calibration curve and is not a component of the uncertainty, which is determined by the width of the new calibration diagram.

In case b) the calibration diagram must be able to yield compatible results of the measurement for any value of the influence quantity within the operating range, and may therefore be constructed as the envelope of the calibration diagrams correspondent to rated values of the influence quantity all over the specified operating range. Its boundary is determined by the outer boundaries of the diagrams correspondent to the two extreme operating conditions, those with higher variation (Figure 4). The variation is now a factor in the determination of the uncertainty, being the major component of the width of the diagram parallel to the R axis. Unless the extreme operating conditions result in diagrams symmetrical with respect to the diagram obtained in reference conditions, the calibration curve in operating conditions will be different from the one in reference conditions.



M = axis of the measure-values, in units of measurement

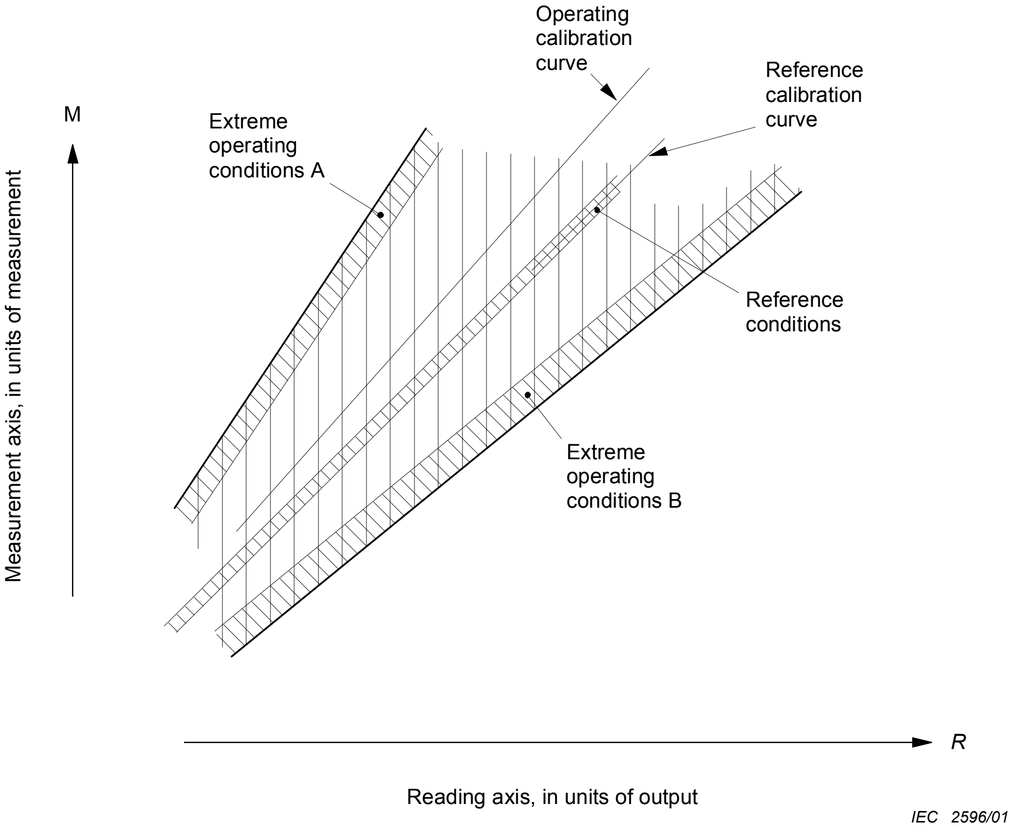
R = axis of the indications, in units of output

Figure 3 – Calibration diagram in different operating conditions

When the operating conditions allow for two or more influence quantities to assume simultaneously values outside the reference range, the situation is more complicate because the effects of the several influence quantities cannot be expected, in principle, to obey simple sum rules or to combine statistically. One can however find out, by experiment or through experience, the combination of rated values of the influence quantities that yields the highest overall variation in either direction, and use these two extreme operating conditions as in Figure 4 to determine or verify the boundary of a calibration diagram valid for the rated operating conditions.

6.3 If there is an IEC product standard which relates to the equipment, written in terms of "limits of maximum error", the limit of uncertainty for any given set of operating conditions shall be specified in accordance with that standard. The specification shall be drafted in terms of the uncertainty resulting from the calibration diagram constructed on the basis of the limits of error set by the standard, paying due attention to the way the "maximum error" is defined.

NOTE In practice, for instruments with the scale marked in units of measurement, since the calibration diagrams are usually narrow strips with parallel or slowly divergent boundaries and the uncertainty can hardly be defined at better than 5 %, limits of maximum error and limits of uncertainty are expressed by the same number (if, of course, they refer to the same statistical ambience).



M = axis of the measure-values, in units of measurement

R = axis of the indications, in units of output

Figure 4 – Calibration diagram for extended operating conditions

6.4 For all other equipment, the specification of limits of uncertainty may give one or more of several types of information, described in the following subclauses.

The subclauses offer a choice between different specifications for the allowed operating conditions with different amounts of the information needed to supply a trustworthy calibration.

6.4.1 Limits of intrinsic instrumental uncertainty

This option specifies limits of intrinsic instrumental uncertainty only with respect to the reference conditions.

The calibration diagram exists only for the reference conditions.

This option calls for the lowest amount of calibration work, but imposes the narrowest limits to the operating conditions, as the instrument is supposed to be operated only in the narrow reference range. Therefore the specification of limits of uncertainty is very seldom limited to this subclause, though it might be used for laboratory instruments meant only for calibration purposes.

6.4.2 Limits of intrinsic instrumental uncertainty with variations for a single influence quantity

This option specifies limits of intrinsic instrumental uncertainty with respect to reference conditions and specifies the variations with respect to rated operating conditions for single influence quantities.

This option allows to operate the instrument with *one* influence quantity outside the reference range while all other operating conditions are contained within their reference range.

In principle the specifications shall be drawn in such a way as to allow the construction of a calibration diagram like that in Figure 3 for any value of the variated influence quantity within the operating range. The values of the influence quantity for which the variations are determined shall have the same tolerance as its reference value. If the uncertainty of the measurement obtained with the variated influence quantity is wider than the intrinsic instrumental uncertainty, its wider size shall be specified. The wider uncertainty assigned to the shifted calibration diagram takes into account the uncertainty with which the variation itself is specified, and the tolerance that the user is expected to respect in measuring the competent influence quantity.

The information brought about by this specification may be utilized by the user in two different ways:

a) if the user knows the value of the influence quantity at which he is operating, with the specified tolerance, he may use the variation as a correction of the reading-value, and compute the result of the measurement with uncertainty equal to the limit of intrinsic uncertainty, or to the wider size specified for measurement at variated value of the influence quantity;

b) if the user does not know at which value of the influence quantity he is operating, but only that it lays within a given range, he may use the variations for the lower and upper limit of the range for constructing a calibration diagram like the one in Figure 4 from which to compute the result of the measurement.

NOTE 1 In case b) the variation is used to define a limit of operating instrumental uncertainty as considered below in 6.4.4, with an operating range for the influence quantity customized on the basis of the user's data. For instruments with scale marks in units of measurement, i.e. with calibration diagrams as in Figure 2, the uncertainty will be of the order of the intrinsic uncertainty plus the range correspondent to the extreme variation, but care must be taken in computing it, especially if the operating range of the influence quantity is asymmetrical with respect to the reference range: one has to refer to the diagram because the variations are segments parallel to the R-axis while the uncertainty is given by segments parallel to the M-axis.

NOTE 2 This option may be convenient when one influence quantity is dominant with respect to the others.

6.4.3 Limits of intrinsic instrumental uncertainty with variations for several influence quantities

This option specifies limits of intrinsic instrumental uncertainty with respect to reference conditions and specifies the variations with respect to rated operating conditions for several influence quantities.

This option allows to operate the instrument with *more than one* influence quantity outside the reference range while all other operating conditions are contained within their reference range, *if* one knows the way in which the effects of the different influence quantities are compounded. It may be used when the effects combine with very simple laws, e.g. linearly.

The specifications shall be drawn with the same conditions expounded above in 6.4.2, with explicit, unambiguous statements on the way the several variations are to be combined. The information may be utilized as above in 6.4.2.

6.4.4 Limits of operating instrumental uncertainty for single influence quantities

This option specifies limits of intrinsic instrumental uncertainty with respect to reference conditions and also specifies limits of operating instrumental uncertainty with respect to rated operating conditions for *one* influence quantity.

NOTE The limit of operating instrumental uncertainty is usually obtained from the variations correspondent to the lower and upper limits of the rated operating range, by constructing a calibration diagram like the one in Figure 4. The same observations apply as in the notes to 6.4.2.

6.4.5 Limits of operating instrumental uncertainty

This option specifies limits of intrinsic instrumental uncertainty with respect to reference conditions and specifies limits of operating instrumental uncertainty with respect to the rated operating conditions for all influence quantities.

This option allows the widest operating conditions but calls for the highest amount of calibration work, as in principle the validity of the calibration diagram should be checked for any combination of values of the several influence quantities within their operating ranges.

However in practice the actual calibration work may be much lower, because the experience accumulated on the performance of measuring instruments and on the variations due to the several influence quantities may allow the manufacturer to determine which are the worst combinations of influence quantities, i.e. those combinations which cause the reading-value to be the farthest away from the reading-value in reference conditions. If such a knowledge is available, then it is matter of carrying out a verification of calibration in just two well-defined sets of conditions beside the reference set (or even one if symmetry obtains).

NOTE 1 The limit of operating instrumental uncertainty may be obtained from a combination of the variations correspondent to the lower and upper limits of the rated operating ranges of the several influence quantities *if* the law of combination of their effects is known. In practice it is easier to determine the combination of values likely to produce the bigger overall variation than to determine a combination law for the variation valid all over their operating range.

NOTE 2 When the limit of operating instrumental uncertainty is given, the user is not much concerned with the limit of intrinsic instrumental uncertainty, unless it is planned to use the instrument both for field work and laboratory work, which is most unlikely. If the specification of the intrinsic instrumental uncertainty is skipped, the calibration work is correspondingly reduced.

NOTE 3 The limit of operating instrumental uncertainty may be specified, if convenient, for different sets of operating ranges: for instance, one may specify that a given limit is valid for a temperature range (T'_a to T''_a) and a pressure range (P'_a to P''_a), or for another temperature range (T'_b to T''_b) < (T'_a to T''_a) if the pressure range is (P'_b to P''_b) > (P'_a to P''_a).

6.5 Several limits of instrumental uncertainty may be stated with respect to several stated sets of rated operating conditions.

6.6 The limits of uncertainty may be specified in absolute, relative, or fiducial terms. In some cases the limit may also be expressed as the sum of an absolute term and a relative or fiducial one. The value to which a fiducial term is referred shall be clearly stated. That same value shall be used when more than one limit is specified.

6.7 For the utilizer of the instrument, the instrumental uncertainty is an imported uncertainty, supplied by the manufacturer or calibrator of the instrument, to be treated as a component of uncertainty of category B (see Introduction). The statement of a limit of uncertainty shall therefore be accompanied by all the relevant information on the method used in determining it, in order to allow the utilizer to use it at best in assessing the uncertainty of his measurements. If the limit of uncertainty is determined by verifying compliance with a predefined calibration diagram, as more often is the case, the utilizer has no real choice other than assuming for it a rectangular distribution in combining its uncertainty with other ones. If however the limit is assessed by statistical inference, as the case may be for the intrinsic instrumental uncertainty alone or with single variations, then a suitable information on the statistical distribution will allow the utilizer a better assessment of the uncertainty of his measurements.

7 Specification of influence quantities

The specification of influence quantities is a key factor in evaluating and expressing the performance of a measuring instrument.

7.1 The higher the performance required of an instrument, the more critical is the determination of the influence quantities and the other operating conditions. On the other hand, the more detailed and stringent is the specification of the operating conditions, the narrower is the field of usage of the instrument. A sort of inverse correlation exists between the accuracy class of an instrument and its usage group. The progress in instrumentation consists not only in improving the accuracy of instruments for laboratory usage in closely controlled operating conditions, but also in extending the possibility of measurement to tougher and rougher operating conditions and improving the accuracy of instruments designed for wider usage groups.

7.2 The specifications on the performance of a measuring instrument should list all the pertinent influence quantities and their allowed range. A pertinent influence quantity is any quantity belonging to the environment, the measured system, or the measuring equipment, whose variation within its specified range has a non negligible effect on the relationship between the indication and the measure-value (see 3.1.14). It follows that a specification of range is implied even in the statement that a certain quantity is not a pertinent influence quantity. Indeed, for instance, the absence of air pressure from the list of influence quantitites for a given instrument does not mean by itself that the instrument may be operated inside a high-vacuum jar: it only means that no significant effects occur within the usual range of variation of the air pressure, which implies an agreement on which range of values may be considered as "usual". The classification of usual ranges of potential influence quantities in *usage groups* is a useful means for avoiding long, incoherent, repetitive lists of specifications for influence quantities.

For the specification of the influence quantities and their ranges the following criteria are indicated.

7.2.1 The expression of the performance of a measuring instrument shall include a statement about the usage group allowed for the instrument, or a complete list of the allowed ranges for any quantity that may be related to the measurement.

7.2.2 In absence of classifications into usage groups offered by specific standards, reference shall be made to the following usage groups with their rated ranges of use and limit ranges as thereby specified:

Group I for indoor use and under conditions which are normally found in laboratories and factories and where apparatus will be handled carefully;

Group II for use in environments having protection from full extremes of environment and under conditions of handling between those of groups I and III;

Group III for outdoor use and in areas where the apparatus may be subjected to rough handling.

7.2.3 In specifying reference conditions the reference ranges for temperature, relative humidity and air pressure should preferably be taken from IEC 60851-5.

7.2.4 A potential influence quantity is considered to have a negligible effect if the variations associated with its values at the extremes of its rated operating range are lower than 10 % of the intrinsic uncertainty, or lower than the component of uncertainty due to the quantization of the reading-values (see 3.1.12, note 3). Otherwise it shall be treated as an influence quantity and its effects specified in one of the ways expounded in 6.4.

7.3 Time should be treated as an influence quantity under two aspects:

a) the *drift* of certain performance characteristics: the ways of accounting for the drift have to be expounded in specific standards;

b) the *age* of the calibration diagram: how long a calibration diagram is expected to remain valid after the last verification of calibration, and how this period of validity may be related to the age of the instrument itself, is a much debated issue that has not yet received normative answers. The definitions on the performance characteristics are so worded as to imply that such characteristics are valid for an indefinite period of time once they have been determined, though no one really expects them to last forever.

7.4 The trend in modern instrumentation is toward multi-sensor equipment able to measure the influence quantities and built-in microprocessor software able to correct for their influence. In such a type of instrumentation the way of treating the influence quantities depends very much on how the software is addressed. For the programmer of the software the variations associated with the values of the influence quantities outside their reference range shall be determined in the calibration procedures and introduced as parameters for the elaboration of the signal into the indication finally displayed (see 6.4.2). For the user, instead, the same quantities are no longer even to be considered as influence quantities because their compliance with the allowed range is automatically checked and their influence automatically corrected: they no longer affect the relation between indication and measure-value because the indication is adjusted within the rated limit of uncertainty. It is all a matter of deciding whether the verification of calibration includes the software or not. A good understanding of the effects of the influence quantities is in order if user adjustments of the software are possible.

8 General rules for compliance testing

Compliance testing consists of verifying whether the indications supplied in correspondence with known measurands stay within the range prescribed by the calibration diagram to prove that the indicated values comply with the specified limits of uncertainty.

The requirements covered by this standard apply to both type testing (carried out on one or a few specimens of a type of instrument) and routine testing (carried out on each specimen).

When relevant, the test methods of specific IEC standards shall be used.

Only values with specified limits can be considered subject to testing. Values given without limits are just for general information, and cannot be the object of compliance testing.

If limits are specified, compliance tests shall be carried out under the conditions indicated in the pertinent standards issued for the several kinds of instruments.

In the verification of calibration the operating conditions shall stay within the range for which the calibration diagram was defined. The verification of calibration should be carried out with test measurands known and with uncertainty negligible with respect to the uncertainty assigned to the instrument by the calibration diagram. If this is not possible, and pertinent specific standards do not specify otherwise, the verification may be considered positive if the result of the measurement yielded by the instrument under verification is compatible with the value and uncertainty of the test measurand, with the appropriate correlation coefficient. If the verification of calibration yields a negative result a new calibration of the instrument should be performed.

It may be worth pointing out that an adjustment is no substitute for a calibration or verification of calibration. Rather, after any adjustment a verification of calibration should be performed, unless it is matter of routine adjustments according to procedures fully accounted for under the operating conditions for which the calibration diagram is valid.

The measurand used for the adjustment should be known with uncertainty negligible with respect to the uncertainty of the instrument.

Annex A
(informative)

Conceptual and terminological evolution from "error" to "uncertainty"

The evolution from the concept of "error" to the concept of "uncertainty" for evaluating measurement results implied some readjustment of the basic metrological terminology, which is worth discussing in order to avoid misunderstandings in people still accustomed to the traditional approach. This evolution was due to the inadequacy of the traditional approach in terms of "true value" and "error", an inadequacy that came more and more to the fore with the development of modern instrumentation, strongly based on automatic elaboration of signals within the instrument.

In the traditional approach the measurand is supposed to be represented by its true value, a single real number tied to the unit of measurement, but the instrument is unable to yield this true value and indicates a value different from the true one by an additive "error" with "random" and "systematic" components. The true value however can never be known, hence also the error is indeterminate: the most one can do is to estimate a limit for it, a "maximum error" within which the actual error is supposed to lay, and thereafter estimate an interval of values within which the "true" one is expected to lay. In practice this interval could not be assessed by reference to the unknown "true value", but by the compatibility of the measurements, i.e. by their "staying within the error" (meaning the "maximum error"). Moreover, as a clear distinction was made between "precision" and "accuracy", meant as the ability to have small random and systematic errors respectively, there was no term to describe the overall performance of an instrument or a measurement. Therefore the operative measurement world began to reason in terms of "uncertainty", meaning with this term a representative width of a set of values ensuring measurement compatibility.

The CIPM Recommendation of 1980 overcame the traditional distinction between "random" and "systematic" errors, for which no sum rule could be given, by suggesting to classify the components of uncertainty into those that could be reduced by increasing the number of measurements (category A) and those that could not (category B). The GUM followed suit, analyzing how to combine several components, and gave a definition of uncertainty without reference to the notion of true value (contextually criticized).

This definition of uncertainty (see 3.1.4) 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.

To begin with, the definition of "result of a measurement", meant as the expression representing the measurand, shall be consistent with the notion that a whole dispersion of values can be attributed to the measurand. Therefore definition 3.1.2 speaks of a set of values, seen as an interval, that is suitably expressed by its mid element and its half-width, referred to as "value" and "uncertainty". It is the uncertainty that determines the size of the set, and the mid element is just a convenient peg where to hang the set, and does not represent the measurand better than the other elements: it is the whole set that represents the measurand. While in the traditional approach the error was an a-posteriori judgement on the validity of the assigned value, the uncertainty is an intrinsic component of the result: no result of measurement should be expressed without the uncertainty (which can be indicated conventionally in the context). For example, the current flowing in a given resistor is given as 149 mA ± 1 mA: the measurand is represented by the whole set from 148 mA to 150 mA; the milliampere is the unit of measurement; 149 mA, the central element of the set, is the measure-value; ±1 mA, the half-width of the set, is the uncertainty of the measurement.

As the measurand is described by a whole set of values, the passage from the indication of the instrument to this description cannot be treated in terms of a "correction for errors" of the indication itself. Moreover, 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 description of the output of the instrument, i.e. the indication (see 3.1.5), and the description of the measurand, i.e. the final result of the measurement that includes the uncertainty (see 3.1.2): the indication allows to know the measurement result through the calibration of the instrument (see 3.1.6 and 6.1).

The information brought in by the calibration is synthetically represented in the calibration diagram (see 3.1.7 and 6.1) by a strip in the coordinate plane of the reading-values and measure-values. A strip is needed because one has to know which value *and* uncertainty to assign in correspondence of any indication – it is not simply a matter of "correcting" the reading-value. The strip is suitably represented by giving its mid line, the calibration curve (see 3.1.8 and 6.1), and its half-width, the uncertainty.

Examples:

- Indication of an ammeter with 100-division scale: 80 divisions. The calibration diagram of the instrument tells that, in the rated operating conditions (see 3.3.13), with this reading one can assign as the result of the (direct) measurement: 8,0 A ± 0,1 A. For user convenience this information may be supplied by marking the scale in amperes (1 A for 10 divisions) and by an index of class of accuracy stating that the uncertainty is ±1 % of the full-scale value (including the reading uncertainty). Such scale marks, however, are only a short-cut for the calibration curve (see 6.2), and do not mean that the instrument yields a value in amperes to be eventually corrected for errors.
- Indication of a force-to-voltage transducer: 50 mV. The calibration diagram of the transducer shows that, in the rated operating conditions, with this value one can assign as the result of the (direct) force measurement: 210 kN ± 4 kN. This information may be supplied in the form of a table of correspondence between indications and (measure) values with associated uncertainty ranges.
- Indication of an overheating warning device: "on" (i.e. lamp lighted). The calibration diagram of the device shows that, in the rated operating conditions, when the lamp is on the temperature is higher than 90 °C ± 5 °C. This information may be supplied by the instruction note of the device. Note that in a measurement of this kind the measurand is not the temperature in itself, but the two classes of temperatures above (= "on") and below (= "off") the threshold, and the uncertainty interval applies to the threshold.

The calibration curve plots the relationship between the indication of the instrument and the "indicated value" of the measurand (see 3.1.9), that is its measure-value in the case of a correctly executed direct measurement, or an element for the computation of the result of the measurement in the case of indirect measurements (including measurements by repeated observations – see 3.2.9), a computation that, in any case needs also the uncertainty associated to the indicated value by the calibration diagram.

In the traditional approach the problem situation now treated under the heading "calibration" was addressed in terms of "scale marking" or "gauging", meaning the operation of fixing the positions of the scale marks of an instrument (see VIM 4.29), while the term "calibration" referred to the operation that establish the relationship between the values thus indicated and the (conventionally true) values of standards (see VIM 6.11). It was taken for granted that the scale marks were labelled in the units of measurement of the measurand (or multiples thereof). While this terminology was quite natural for the classical instruments where a pointer is mechanically driven across a scale engraved on brass, it is not suited to more elaborate instruments, and a more general terminology was adopted, suitable for all situations.

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 (see 3.1.10). 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 such terms two results of measurements are deemed to be compatible with each other when they are expressed by numeric intervals such that $|V_1 - V_2| \leq U_{12} = \sqrt{(U_1^2 + U_2^2 - 2rU_1U_2)}$, where U_{12} is the uncertainty of the difference of the two measurements and r the correlation coefficient of the two measurements. If the two measurements are completely uncorrelated, then $r = 0$ and the two intervals must be partially overlapping for compatibility; if they are totally positively correlated, then $r = +1$, $U_{12} = U_1 - U_2$, and compatibility requires complete overlapping; if they are anticorrelated with $r = -1$, then $U_{12} = U_1 + U_2$ and the overlapping of the two intervals may be reduced to one common element for compatibility. The assessment of compatibility is therefore tied to a judgement on the correlation between the several measurements, which may not be easy, and will require much care in the statistical elaboration of the calibration data. For the purposes of this standard we consider that measurements carried out at the opposite extremes of the combined effect of the operating conditions are to be considered anticorrelated with $r = -1$ (see 6.1).

Example:

- the following measurements of the capacity of a condenser are all compatible with one another:
  a) 322,5 ± 0,2 pF, b) 322,6 ± 0,2 pF, c) 322,58 ± 0,02 pF, d) 323,0 ± 0,5 pF. Another uncorrelated result, e) 322,52 ± 0,02 pF, is not compatible with c) but is still compatible with the other ones. If the measurements are correct, this means that the capacity has changed between measurements c) and e); the change was relevant for measurements with uncertainty ±0,02 pF, while for measurements with uncertainty ≥ ±0,2 pF the capacity would have been considered constant.

An obvious consequence of the notion that 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. One cannot state, e.g., that the instrument shall be operated at 25 °C, but rather that the reference range for the influence quantity "temperature" is 24 °C to 26 °C (or 25 °C ± 1 °C), which means that the temperature T must satisfy the relation $24\ °\mathrm{C} \leq T - U < T + U \leq 26\ °\mathrm{C}$. Obviously the temperature has to be measured with uncertainty $U \ll 1\ °\mathrm{C}$, otherwise the condition would be satisfied only occasionally.

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. The main problems came from the treatment of the variations, because on one hand the performance of the instruments could not be limited to the reference conditions for which the "intrinsic (maximum) error" was defined, and on the other hand no economical criterion could be devised for combining the several variations (also for the terminological and conceptual ambiguities by which it was not clear whether they were treated as a component of the "systematic error" or as a computational device for computing the "maximum operating error"). As the distinction between electric and electronic measurement instruments began to wane, IEC 60359 (1987)[2] offered a standard for both kinds of instruments and tried to overcome the difficulties by treating the variations as sources of independent uncorrelated errors with equiprobable distribution. While this approach allowed an easy mathematical procedure for computing the "maximum error", it was devoid of physical bases, as most influence quantities are certainly neither uncorrelated nor equiprobable. Besides, the problem was still addressed in terms of "error". Now that the separation between electric and electronic measurement instrument is decidedly obsolete, and the notion of uncertainty has prevailed, it is high time to address the problem situation in general and modern terms.

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[2] IEC 60359:1987, *Expression of the performance of electrical and electronic measuring equipment* (cancelled and replaced by the present edition)

Annex B
(informative)

Steps in the specification of performance

The means and procedures for determining the performance of the instruments are outside the scope and object of this standard, which is addressed to the expression of such performance. They are usually the object of IEC product standards pertaining to particular types of equipment, that should now be redrafted in terms of the GUM philosophy. A general standard for the implementation of the GUM with respect to the determination of instrumental uncertainties would be quite useful for uniformity.

However, it is worthwhile to expound here, in the form of a block diagram at the informative level (Figure B.1) the steps to be taken to express the performance in the terms of this standard.

The first step is of course the specification of the measured quantity and the measuring range (see 3.3.9). This may be followed by the specification of the output format, i.e. the unit in which the indication is presented (see 3.1.5, 3.2.2).

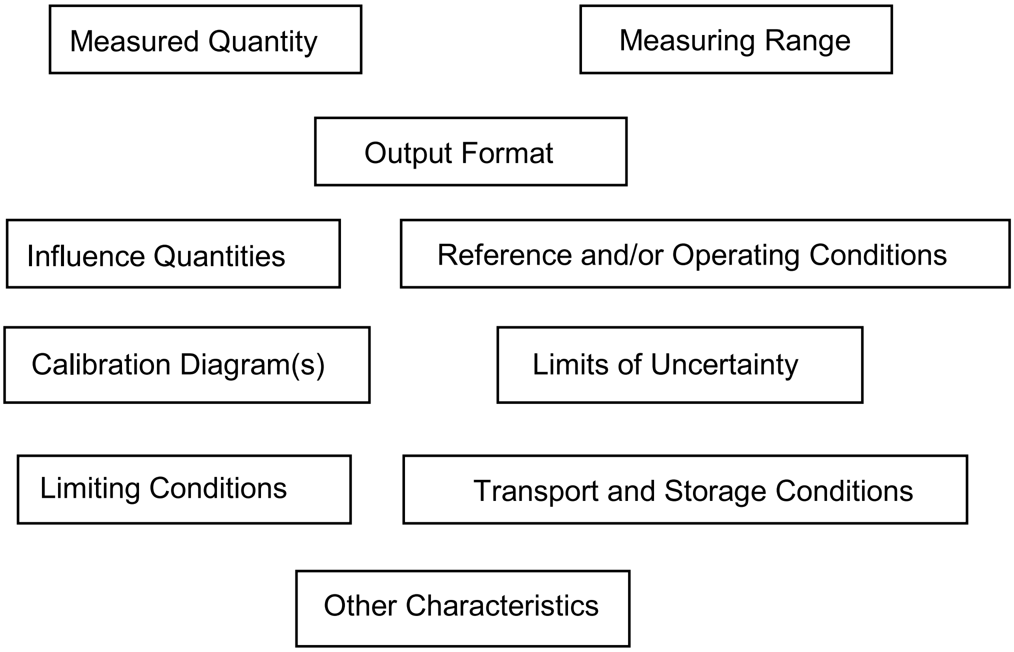

Figure B.1 – Steps in the specification of performance

If the output format is a display on an arbitrary scale, or a signal to be read by another instrument, then its specification does not require calibration work: the calibration diagram will be produced thereafter by the calibration (see Figure 1). When the output is meant for another instrument, or an external display, the specification of the format shall include the specification of the coupling characteristics required for the readout device.

If, on the other hand, the choice is made of labelling the output directly in the units of measurement of the measurand (see Figure 2), in principle this labelling operation presupposes a calibration. If the labelling is made before the calibration of the instrument on the basis of previous experience with similar instruments, two options are open:

a) the labelling is taken as definitive, which means the calibration curve has been predetermined as a straight line with unit slope (see Figure 2), in which case the subsequent calibration will only determine how wide is the calibration diagram astride this predetermined calibration curve, i.e. the uncertainty;

b) the labelling is considered just a way of describing the reading-value, in which case the subsequent calibration will supply a full calibration diagram, bisected by a calibration curve, which correlates any reading-value to the measure-value with uncertainty.

Option b) may give rise to misunderstandings if one forgets that it is only matter of labelling the output: the calibration will not supply a "correction" to the measurement result, but the measurement result itself (value and uncertainty).

With the obsolescent pointer-on-scale instruments this labelling operation (traditionally called "gauging" or "scale marking") was effected on a once and for all basis, which in the philosophical framework of the times, was also a source of theoretical difficulties: the operation was meant for option a) above, but then the facts of instrumental life required shifting to option b) without acknowledging that it was a matter of labelling. The instrument did not behave as it was supposed to do, the "error" was seen as due to "imperfections" of the instrument and the "calibration" suggested additive "corrections" to the result of the measurement to compensate the so-called "systematic error". With the modern digital-output instruments, the operation is a matter of setting the parameters of the analog-to-digital converter and its coupling to the readout display, a setting which may, and indeed more and more frequently does, involve software. Strictly speaking, it is a matter of an adjustment, i.e. providing given indications corresponding to given values of the measurand (see 3.2.13), and one should be careful not to confuse adjustments with calibration. Often the so-called self-calibrating instruments only readjust the output to the preset calibration curve: this is quite useful if one is sure that the width of the calibration diagram is not altered in the process, otherwise it is misleading.

Thereafter comes the specification of the relevant influence quantities and their range (together with other relevant conditions). Here an option shall be taken on whether to specify

a) only reference conditions;

b) reference and rated operating conditions;

c) only rated operating conditions;

depending on the field of usage of the instrument, its level of uncertainty, and the amount of calibration work one is disposed to face (see 6.4 and 7.1). If option b) is taken, one shall then choose whether to express the results in terms of limits of intrinsic uncertainty and variations (see 6.4.2 and 6.4.3) or limits of intrinsic uncertainty and limits of operating uncertainty (see 6.4.4 and 6.4.5). The amount of calibration work (direct or inferred from previous experience) is higher when one specifies the limits of operating uncertainty rather than only the variations, because one has to express how the several variations combine with each other and how the uncertainty changes with respect to the reference conditions.

After the limits of uncertainty are specified, one shall also specify the limiting conditions (see 3.3.15 and 3.3.16) and the storage and transport conditions (see 3.3.17 to 3.3.19).

A possible further step is the specification of performance characteristics that are not deducible from the calibration diagram (and are not addressed in this standard) as, e. g., the resolution or the response characteristics in transient operations.

Bibliography

a) IEC Publications

IEC 60051 (all parts), *Direct acting indicating analogue electrical measuring instruments and their accessories*

IEC 60068 (all parts), *Environmental testing*

IEC 60529:1989, *Degrees of protection provided by enclosures (Code IP)*

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IEC 60721-3-0:1984, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Introduction*

IEC 60851-5, *Winding wires – Test methods – Part 5: Electrical properties*

b) Other Publications

CIPM Recommendation INC-1 (1980)

CIPM Recommendation 1 (CI-1981)

CIPM Recommendation 1 (CI-1986)

ISO/IEC INT-VOC-MET:1993, *International Vocabulary of Basic and General Terms in Metrology*

UNI 4546: 1984, *Misure e misurazioni. Termini e definizioni fondamentali – Norma italiana CDU 681.2:001.4, 1984 (Measures and measurements – Fundamental terms and definitions. Italian standard)*

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

This European Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies (including amendments).

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-300	2001	International Electrotechnical Vocabulary - Electrical and electronic measurements and measuring instruments Part 311: General terms relating to measurements - Part 312: General terms relating to electrical measurements - Part 313: Types of electrical measuring instruments - Part 314: Specific terms according to the type of instrument	-	-
ISO/IEC GUIDE EXPRES	1995	Guide to the expression of uncertainty in measurement (GUM)	-	-

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