UNCERTAINTY

Uncertainty of measurement and error limits in legal metrology

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Abstract

Whenever standards are used for testing measuring instruments, they must be traceable to national or international standards. When the instruments have been calibrated, the measurement uncertainty is normally given on the certificate. If, however, the measuring instruments have been verified, the measurement uncertainty is not always quoted. This may be due to the maximum permissible errors (mpe) both on initial verification and in service. Generally, the requirements for calibration and testing are met by legal metrology, however some measures may have to be taken to ensure transparency and documentation.

Introduction

Due to the ever-increasing significance of quality management, a growing number of companies throughout the world have had their quality systems certified to the ISO 9000 series of standards. Both certification bodies as independent bodies for conformity assessment of products and calibration and testing laboratories need quality systems; in Europe these must meet the requirements found in the EN 45000 series of standards. These standards require measuring and test equipment to be traceable to national or international standards. As a rule, the quantities to be measured are traceable to SI units in an unbroken chain of comparison measurements carried out by competent bodies.

The concept of traceability not only requires an unbroken chain of comparison measurements, but also a statement and documentation of the measurement uncertainties. The statement of measurement uncertainties with reference to the standards used is an essential part of every calibration. Competent bodies will therefore normally accept calibrated instruments as test equipment within a quality management framework. The use of legally verified instruments for this purpose sometimes presents problems, since although the mpe's for the instruments are known, no measurement uncertainties are explicitly given. These problems are due to the different tasks and objectives of verification and calibration as well as to a lack of understanding between the two systems.

The authors hope to clearly identify the differences, but, at the same time, must point out that the same principles apply to the identical metrological aspects of both activities. No matter whether the metrological activities are performed in the regulatory or the non-regulatory areas, they must not deviate by more than is justified by the given objectives.

1 Objectives of verification

1.1 Historical development

The units of mass, volume and length are important since in commercial transactions their measurement determines the price. In the past, various interests as well as regional and historical differences led to differing units and systems. As cross-border trade increased in significance, pressure grew for harmonization; this resulted in the introduction of the SI system which not only became the legal basis for official dealings and commercial transactions, but also gained in importance in the non-regulatory field of industrial metrology. An efficient metrological infrastructure is the basis of all modern industrial societies and from this point of view, legal metrology was the pioneer of uniform measurement.

1.2 Legal requirements

The main objective of legal metrology is to protect citizens against the consequences of false measurements in official dealings and commercial transactions as well as in the labor, health and environment areas. As the interests of the parties concerned by measurements in these areas differ, the characteristics of the instruments used cannot be satisfactorily controlled by market forces. Legislation therefore lays down requirements not only for measuring instruments, but also for measuring and testing methods.

In Germany, these regulations are controlled by European Directives and by the Verification law. For individual categories of instruments, the regulations cover:

- the mpe's both on verification and in service;
- nominal conditions of use;
- susceptibility to external interference;
- electromagnetic compatibility (EMC);
- labeling;
- durability;
- tamper resistance; and
- reverification periods.

Everyone concerned with measurements should have instruments which give correct results within specified mpe's under the local environmental conditions. As the parties concerned by the measurements are not normally metrological experts, and do not have the capability of checking the results they are given, the State therefore takes responsibility for the validity of measurements within the framework of legal metrology.

1.3 Measures and procedures

In order to reach the objectives of legal metrology, both preventive and repressive measures are needed. Preventive measures are taken before the instruments are placed on the market or put into use and include pattern approval and verification. Market surveillance is an example of a repressive measure, and involves inspection of the instrument at the supplier's, owner's or user's premises. Here misuse of the instruments will be detected, and the offence may be punished by a fine.

The manufacturer has to file an application for pattern approval with the competent body. In Germany, this is the PTB; other European bodies as well as PTB are also responsible for European pattern approvals.

At least one sample of the instrument is examined to ensure compliance with the legal requirements. Approval tests and calibrations are carried out, and the results show whether the given requirements are met. It is particularly important to determine whether the mpe's at rated or foreseeable *in situ* operating conditions are likely to be met. The sample instrument is also subjected to quality tests which should guarantee its reliability in use.

For reasons of efficiency, verification usually only requires a single measurement (observation) to be carried out. It is therefore important that the spread or dispersion of measured values is determined during the type approval tests. This determination of so-called *a-priori* characteristic values forms the justification for the evaluation of the uncertainty of measurement on the subsequent verifications.

Upon successful type approval testing, a manufacturer has in principle proven his technical competence to manufacture an instrument that meets the legal requirements.

As pattern approval is a test of the pattern, it is followed by verification testing on each instrument. This ensures that every single instrument conforms with the pattern. After the initial verification validity period has expired, reverification will be done by a verification body. When a single owner (particularly an energy or water utility) has a large number of instruments, reverifications may be carried out on samples. The reverification requirements, in particular the mpe's, are the same as those at initial verification, which means that the measurement uncertainties have to be handled in the same way.

European harmonization allows the manufacturer to carry out conformity assessment on new instruments as an alternative to verification by a verification body. This leads to the need to harmonize the measuring and testing methods, including determination of the measurement uncertainties and accounting for them in conformity assessments. Some relevant terms and definitions are given below.

2 Metrological terms and definitions

2.1 Uncertainty of measurement

According to the VIM (3.9) [1] measurement uncertainty is a "parameter, associated with the results of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand".

Measurement uncertainty is usually made up of many components, some of which may be determined from the statistical distribution of the results of series of measurements and which can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.

Contributions to the measurement uncertainty are:

- the standards used;
- the measuring and test equipment used;
- the measuring methods;
- the environmental conditions;
- susceptibility to interference;
- the state of the object to be measured or calibrated; and
- the person performing the measurement or calibration.

The *Guide to the Expression of Uncertainty in Measurement (GUM)* [2] and document EA-4/02 [3] give detailed information on the determination of measurement uncertainties and a summary of the contributions (cf. Section 3).

2.2 Calibration

The VIM (6.11) [1] defines a calibration as "a set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards". This means that the calibration shows how the measured value or the nominal value indicated by an instrument relates to the true or conventional true values of the measurand. It is assumed that the conventional true value is realized by a reference standard traceable to national or international standards.

Not only the measurement uncertainty but also the environmental conditions during the calibration are significant. The calibration is often carried out in a place with well-known environmental conditions, which leads to low measurement uncertainties. When the calibrated instrument is used in a different environment the measurement uncertainty determined by the calibration laboratory will often be exceeded if the instrument is susceptible to its environment. There can also be a problem if instrument performance deteriorates after prolonged use. The user of the calibrated instrument must therefore consider any environmental or secular stability problems.

2.3 Testing

According to ISO 8402 [4] testing implies the statement that conformity for each of the characteristics was achieved. EN 45001 [5], however, states that a test is a technical process in the sense of an examination to determine the characteristic values of a product, procedure or service.

The quantitative requirements stipulated for instruments refer to the measurement errors, the values of which must not exceed the mpe's. The measurement error itself is in practice recognized to be the result of a measurement minus a conventional true value [1]. Calibration of the instrument over the given measuring range at given environmental conditions is the prerequisite for an assessment of conformity with regard to error limit requirements being met.

Whereas a measurement result implies an uncertainty of measurement, a complete testing result implies an uncertainty of testing. This leads to an *uncertainty of decision* with regard to conformity assessment. A distinction must be drawn between quantitative and qualitative tests, and as a rule a measurement uncertainty can be assigned in a quantitative test. An assessment of any qualitative characteristics of the object under test, e.g. of a measuring instrument, also requires uncertainty statements. This means that the measurement uncertainty determined during the calibration is only a contribution to the total uncertainty.

2.4 Verification

The verification regulations lay down the tests and marking of an instrument. The initial elements of verification are:

- a qualitative test, which is effectively an inspection; and
- a quantitative test, which is almost the same as a calibration.

These two elements of verification are tests in the sense of the EN 45000 series of standards. Once they have been performed, the matter of certification can be considered.

Here the test results are evaluated to ensure that the legal requirements are being met. During this evaluation it is particularly important to establish that the calibration results demonstrate that the mpe requirements are satisfied.

Assuming that the evaluation leads to the instrument being accepted, a verification mark or label must be fixed to it, and, where relevant, tamper evident seals. A verification or evaluation certificate may be issued.

3 Calculation of the measurement uncertainty

Basically, the determination of the measurement uncertainty refers to the calibration inherent in conformity verification (cf. 2.4). Therefore the procedures given in the GUM [2] and in EA-4/02 [3] are applicable:

(a) Defining the objective

As a rule, the basic objective in legal metrology is the determination of the expanded measurement uncertainty (k = 2), for the difference between the measuring instrument under test and the standard.

(b) Drawing up a model function

The model function expresses in mathematical terms the dependence of the measurand (output quantity) Y on the input quantities X_i according to the following equation:

$$Y = f(X_1, X_2, \ldots, X_N) \qquad (1)$$

In most cases it will be a group of analytical expressions which include corrections and correction factors for systematic effects [3].

Where a direct comparison is being made between the indications shown by the instrument under test and the standard, the basic equation may be simple:

$$Y = X_1 - X_2 \qquad (2)$$

Example 1: Testing of a filling station fuel dispenser by means of a standard measuring container

Measurand Y:	Deviation of the indicated fuel volume from that actually delivered
Input quantities X_k related to the instrument to be verified:	Fuel dispenser indication, measuring system temperature, liquid temperature, etc.
Input quantities X_l related to the standard used:	Level indication, deviation of container from horizontal, fuel environment temperatures, foam layer thickness, etc.
Other input quantities X_m:	Loss of fuel during the measuring process due to evaporation or adhesion, incorrect operation, etc.

(c) Type A evaluation of uncertainty contributions

This is done by statistical analysis of a series of observations, normally by calculation of the arithmetic mean value and its experimental standard deviation. The estimates x_i of the input quantities X_i have to be determined, and the standard uncertainties u_i are the standard deviations mentioned above [2], [3].

(d) Type B evaluation of standard uncertainty of input quantities

Method A normally assumes that the measurement values are normally distributed and that the standard uncertainty is indicated in terms of the empirical standard deviation of the mean. When using method B however, the probability distribution to be applied must be considered in more detail.

If the distribution is unknown, and no data from which an uncertainty could be deduced are available, values have to be based on scientific experience. If maximum or minimum tolerances can be assumed (even by approximation), the standard uncertainty has to be calculated on the basis of a rectangular distribution [2], [3]. This is also applicable to measurements with working standards in legal metrology.

Example 2: Measurement with a 50 L standard measurement container

The uncertainty contribution for a 50 L standard measurement container where only the nominal volume and mpe's are given has to be determined by applying the rectangular probability distribution.

mpe $(\Delta V_N / V_N)_{max}$:	0.1 %
Resulting standard uncertainty $u(V_N)$:	$\Delta V_N / \sqrt{3} \approx 29\ \text{cm}^3$

(e) Calculation of the sensitivity coefficients

The sensitive coefficient can be found from the model function by:

- partial differentiation of the model function by the individual input quantities at all relevant values of their estimates:

$$c_i \approx (\delta Y / \delta X_i)\big|_{x_i} \qquad (3)$$

and/or:

- (computerized) numerical variation of the input quantities according to their quantification and taking into account the change in the output.

Experimental determination of the relationship between output and input quantities is also possible.

(f) Compilation of an uncertainty budget

Sources of uncertainty must be listed in tabular form, together with their respective input estimates x_i, standard uncertainties $u_k(x_i)$, and contributions $u_i(y)$ to the uncertainty associated with the output estimate y.

(g) Calculation of the output estimate and of the associated standard uncertainty

The standard uncertainty of the output estimate is determined by adding the contributions $u_i(y)$ in quadrature. This gives the square of the standard uncertainty $u(y)$ of the measurand. It is essential to consider the possibility that some of the contributions may be correlated, and so not truly independent [2], [3].

(h) Statement of the complete measurement result

The complete measurement result includes the output estimate y and the expanded uncertainty of measurement $U(y)$. This identifies the range within which the output will be found with a probability of approximately P = 95 %.

When the measurement uncertainty of a verification is to be determined, it should be remembered that normally only individual measurements are made. This means that evaluation method A may only be applied if relevant *a-priori* data, e.g. for the standard deviation of a certain type of instrument, exist. Logically, the standard uncertainty of the individual measurement, i.e. the standard deviation of a series of observations, will then be included in the output rather than the standard uncertainty of the mean.

As a rule, *a-priori* data are determined in type approval tests. Moreover, for many instrument categories, e.g. fuel dispensers, comprehensive experience or statistical values are available.

Formal application of the above scheme is not sufficient for the determination of the measurement uncertainties. The chief prerequisite for a realistic result is a complete model which is close to reality. Critical and honest evaluation of the estimated values of the input quantities can only be based on sound experience.

4 The significance of measurement uncertainty in practice

4.1 Calibration

A calibration gives a systematic measurement error together with a statement of the measurement uncertainty. This not only relates to the correct value derived from the reference standard, but also takes account of the environment during calibration. The temperature is of particular importance here but humidity, air pressure and electromagnetic fields may also make a considerable contribution to the measurement uncertainty.

As a rule, instruments to be used as reference standards will be calibrated under controlled environmental conditions. If these newly calibrated instruments are then used in the same environmental conditions, it can be assumed that they will have the same measurement uncertainty. When an instrument is being calibrated against such standards, its uncertainty u_s enters into the total uncertainty of measurement u_{meas} as an (uncorrelated) contribution:

$$u^2_{meas} = u^2_s + \Sigma u^2_i \qquad (4)$$

where u_i are contributions to the measurement uncertainty related to the calibration procedure and to the nature of the object under test.

If, on the other hand, a calibrated standard is used in different environmental conditions and after prolonged use, higher uncertainties must normally be assigned.

Calibration therefore makes a statement about an instrument's behavior only at the moment it is carried out. The user must assess on the basis of his technical knowledge whether the calibrated instrument is suitable or not. If a calibrated instrument is to be used to evaluate the uncertainties of measurements and tests under other environmental conditions, particularly strenuous requirements will have to be met. Calibration certificates do not normally contain any statements about the long-term behavior of the object.

4.2 Testing

While the term "measurement uncertainty" is clearly defined and used [1], the term "uncertainty of testing", which means uncertainty as to the properties of the object under test, is not yet harmonized. Proposals for harmonization have been put forward by the European Cooperation for Accreditation of Laboratories (EA) [7].

No matter whether an application is covered by regulations or not, a quantitative test on a measuring instrument should state whether the values determined lie within the mpe. For this reason, a calibration (including a measurement uncertainty statement) is required.

Figure 1 shows possible interrelations between the intrinsic error of a measuring instrument [1], the mpe and the uncertainty of measurement.

In cases a, b and c, the instrument is within the mpe. In case d, non-compliance with the requirements is proven and in cases e and f no unequivocal statement of conformity can be made. Here, the parties concerned must agree on acceptance or rejection of the instrument. This kind of assessment is, *inter alia*, required for the testing through measurement of manufactured items and instruments by ISO 14253 [8].

4.3 Verification

4.3.1 Maximum permissible errors on verification and in service

Verification is a special method of testing covered by regulations laid down by legislation. In OIML Recommendations and in many economies with developed legal metrology systems, two kinds of error limits are defined:

- the mpe on verification; and
- the mpe in service, which in most cases is twice the mpe on verification.

The mpe on verification equals an "mpe on testing" which only applies at the time of the verification. The mpe in service is the one that is legally relevant for the user of the instrument.

Figure 2 explains this approach to the effect that during the time of use of a measuring instrument within the period of the validity of the verification, the indicated measured value will drift to some extent and the uncertainty of measurement will in most cases clearly rise due to the realistic operation conditions and external interference. In particular the following influences must be taken into consideration:

- measurement uncertainty from the metrological test during verification;
- normal operating conditions;
- external interference during normal operation; and
- long-term behavior, drifting, aging and durability.

The mpe on verification may be exceeded here, however requirements regarding the mpe in service must in general be met. As a result, verification implies a high probability that under normal conditions of use the measuring instrument will furnish measurement results within the given mpe's in service during the entire validity period of the verification.

In practice, measuring instruments are considered to be in compliance with the legal regulations:

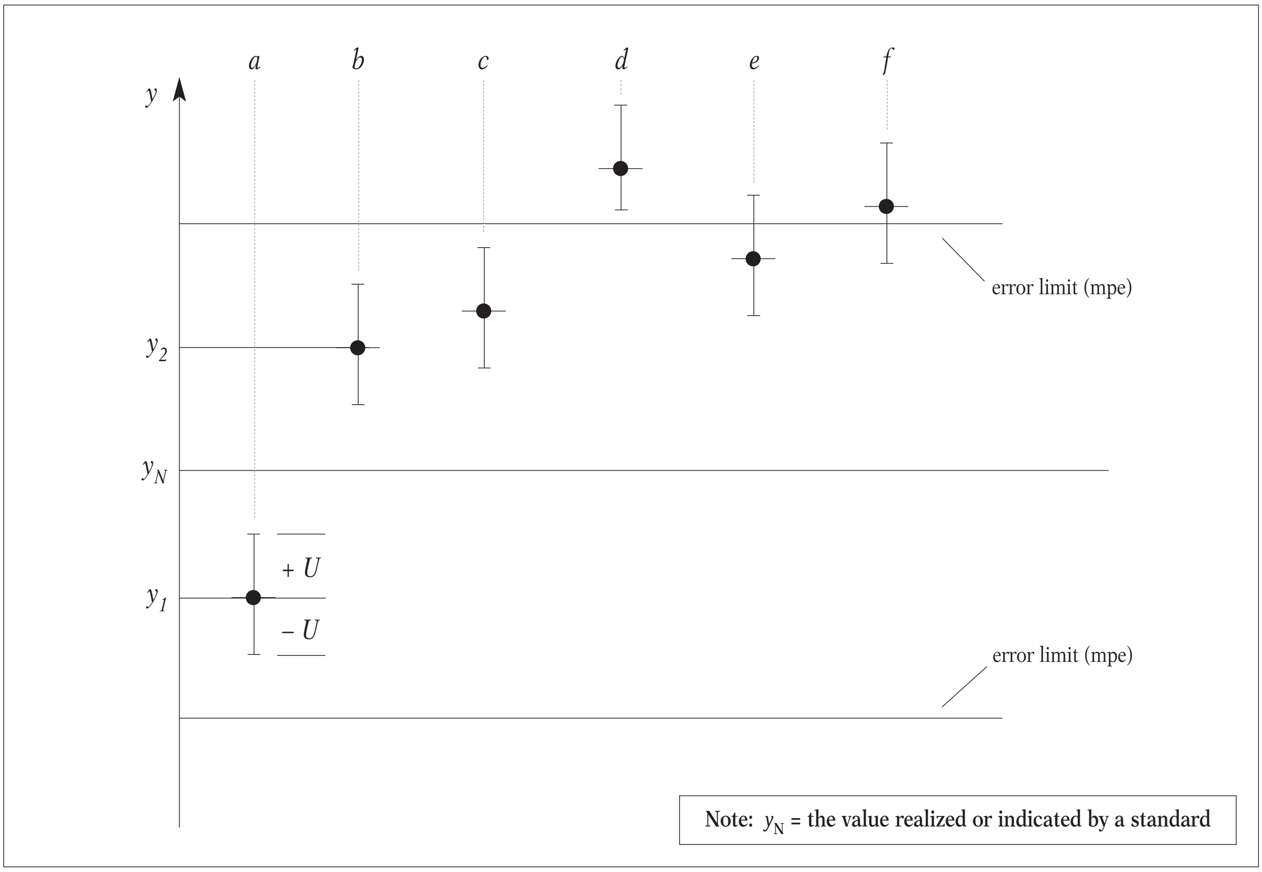

Fig. 1 Influence of the (expanded) uncertainty of measurement of various measurement results y_j on conformity assessment in testing

- if the indicated value is smaller than or equal to the mpe on verification when the test is performed by a verification body under unified test conditions; and
- if the uncertainty of measurement at the 95 % probability level is small compared with the prescribed error limit.

In legal metrology at present, the uncertainty of measurement is usually considered to be small enough if the so-called "one-third uncertainty budget" is not exceeded:

$$U(\mathrm{k} = 2) \leq 1/3 \cdot MPEV \qquad (5)$$

where *MPEV* is the mpe on verification.

The criteria for the assessment of compliance are illustrated in Fig. 3. Compliance with the requirements of the verification regulations is given in cases *a, b, c* and *d*. Cases *e* and *f* will result in rejection, although all the values including the uncertainty of measurement lie within the tolerances fixed by the mpe's in service.

As regards the mpe on verification, the described approach above is called the "shared risk concept": provided that inequation (5) applies, the (systematic) error of measurement determined is not extended by the uncertainty of measurement when one checks whether it exceeds the error limits on verification. In this way there is an approximately shared risk that a test result lying on the extreme edge of the tolerance band may be inside or outside the permissible limit.

Therefore, the mpe on verification of a newly verified measuring instrument will in the worst case be exceeded by 33 %. However, as the legally prescribed mpe's in service apply for the user of the measuring instrument, there is no shared risk in the sense that no measured value - even if the measurement uncertainty is taken into account - will be outside this tolerance band.

So far, the mpe's on verification can be seen as a supporting guide for the conformity assessment of mpe's in service being met in order to take the above-mentioned influences into consideration.

To a far-reaching extent the influence of the operating conditions at the place of use, the effect of interferences and the long-term behavior must be ascertained during pattern testing by the type approval body; here, experience gained with the same category of measuring instruments will be included in the assessment.

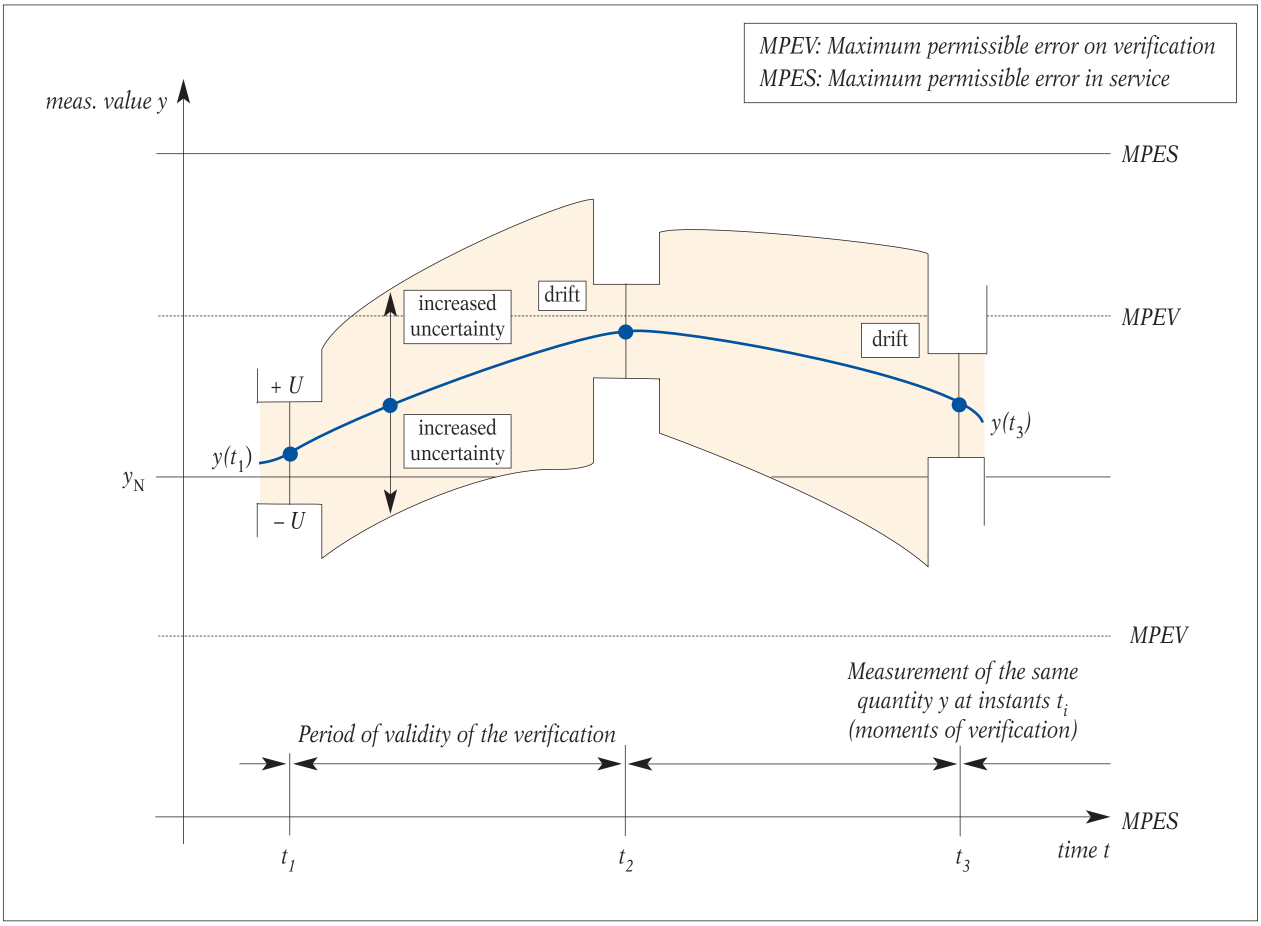

Fig. 2 Consideration of long-term drift and external influences by definition of two kinds of error limits: mpe on verification and in service

4.3.2 Standards and testing methods

When carrying out the tests required in legal metrology, the uncertainty of measurement predominantly depends on the reference standards. To ensure that the test is traceable to national standards, the reference standards of the conformity verification bodies are calibrated by the relevant national institute of metrology (in Germany, the PTB). The systematic errors and the measurement uncertainties associated with these reference standards are given on test or calibration certificates.

The verification bodies derive the traceability of their working standards from these reference standards. In most countries with a highly developed legal metrology system, the working standards can deviate from the conventional true value indicated or realized by the reference standard used by no more than one third of the mpe on verification. Here the expanded measurement uncertainty (k = 2) of the measured quantity should be taken into consideration. As the comparison of the standards is performed under laboratory conditions, the measurement uncertainty may be minimized. As a rule, systematic components will predominate the error budget. If the working standard meets the "one-third uncertainty requirement", its systematic error and the measurement uncertainty will not be considered during verification in order to make the metrological tests cost-efficient. When the "one-third uncertainty requirement" (cf. 4.3.1) does not apply, systematic errors have to be individually accounted for.

ISO/IEC DIS 17025 [6], which is a more recent draft standard, also recommends the 1:3 ratio between the measurement error or measurement uncertainty, and the prescribed tolerance. This is a practice which has been applied in legal metrology for many years. The testing periods for standards are also laid down by law.

In verification, metrological testing methods are applied which were optimized and harmonized by the responsible bodies based on the experience of verifying millions of measuring instruments. In Germany, there are about 25 million instrument verifications per year. As long as the prescribed conditions at the place of testing are met, additional external influences and subjective factors will not cause measurement uncertainties to exceed the error limits of the working standards. As a rule these uncertainty contributions are therefore neglected. However, this practice is only acceptable if:

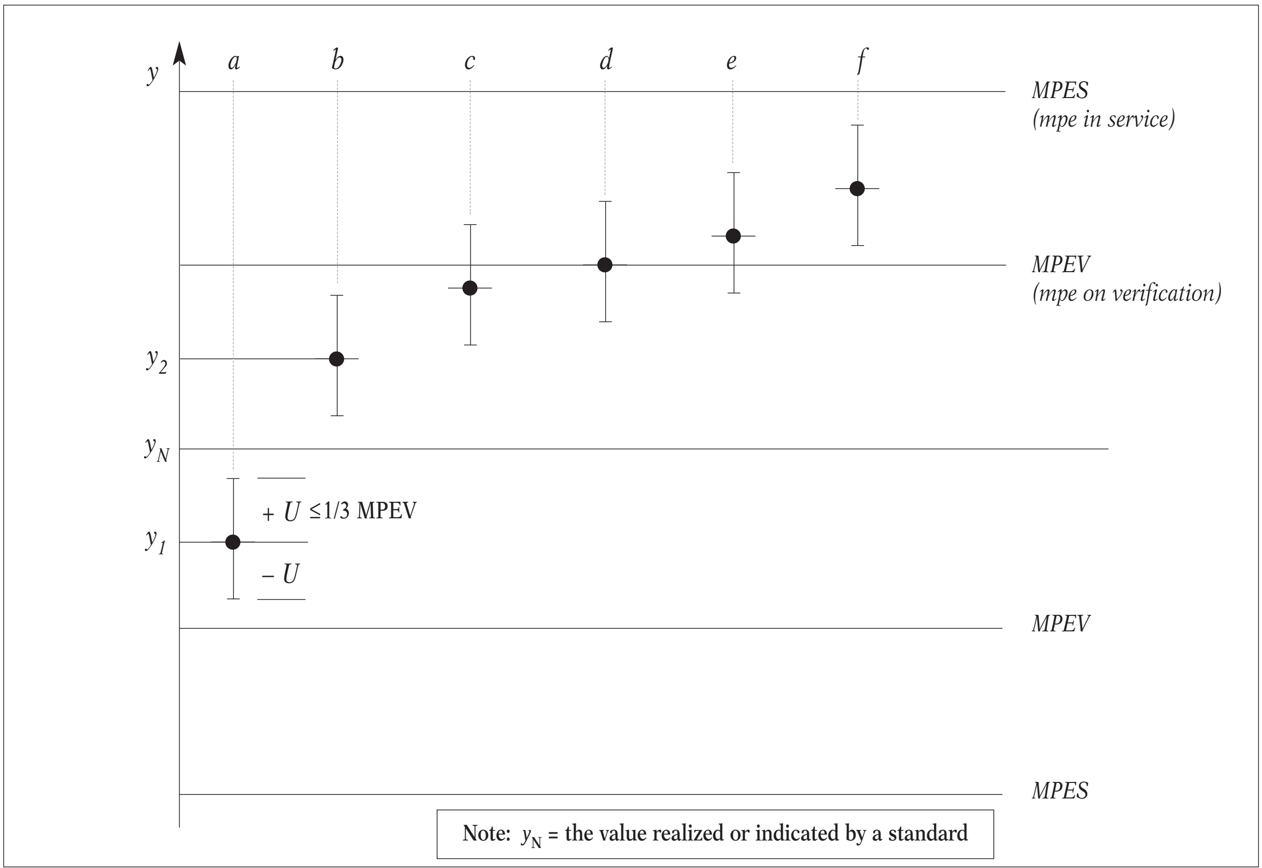

Fig. 3 Influence of the uncertainty of measurement *U* (k = 2) of various measurement results y_i on conformity assessment in verification

- the uncertainty attached to the working standard is clearly within the "one-third uncertainty budget";
- the additional contribution of uncertainties does not contain serious systematic error components; and
- all contributions other than the measurement uncertainty of the standard used total less than 20 % of the mpe on verification.

Example 3 illustrates these relations:

Example 3: Verification of a fuel dispenser

mpe on verification (MPEV)	0.500 %
"One-third uncertainty budget" (0.33 MPEV)	0.166 %
Relative expanded measurement uncertainty (k = 2) of the standard measuring container (58 cm^3; cf. Example 2)	0.116 %
Contribution of measurement uncertainties (k = 2) arising from procedure and external influences (20 % of 0.500 %)	0.100 %
Total measurement uncertainty (added in quadrature)	0.153 %

The measurement uncertainty contribution from the procedure and the external influences is unusually large, amounting to 20 % of the mpe on verification. Despite this, due to addition in quadrature, the total uncertainty in the above example is not much greater than that of the standard, and the "one-third budget" will be met.

The above strategy may also be based on the normally rather high error limits in legal metrology, the "one-third uncertainty budget" being on the safe side as far as the measurement uncertainties are concerned.

However, the effect of ignoring the measurement uncertainties arising from the test procedure and from external influences must be considered critically. If the specified ambient conditions are exceeded in the test, the respective contribution of these uncertainties can increase to more than 20 % of the mpe on verification.

If all the requirements are met, the mpe on verification (MPEV) will in the worst case be exceeded by 33 % (case *d* in Fig. 3).

For reasons of consumer protection and efficient manufacturing of measuring instruments, it is important for competent authorities and manufacturers to have a quantitative estimate of the consequences of the measurement uncertainty in conformity verification on the quality of the instruments to be placed on the market. The following two questions are of particular importance:

- what is the proportion of newly verified measuring instruments to be expected which actually exceeds the mpe on verification?
- what is the proportion of newly verified measuring instruments to be expected which actually exceeds 1.33 times the mpe on verification?

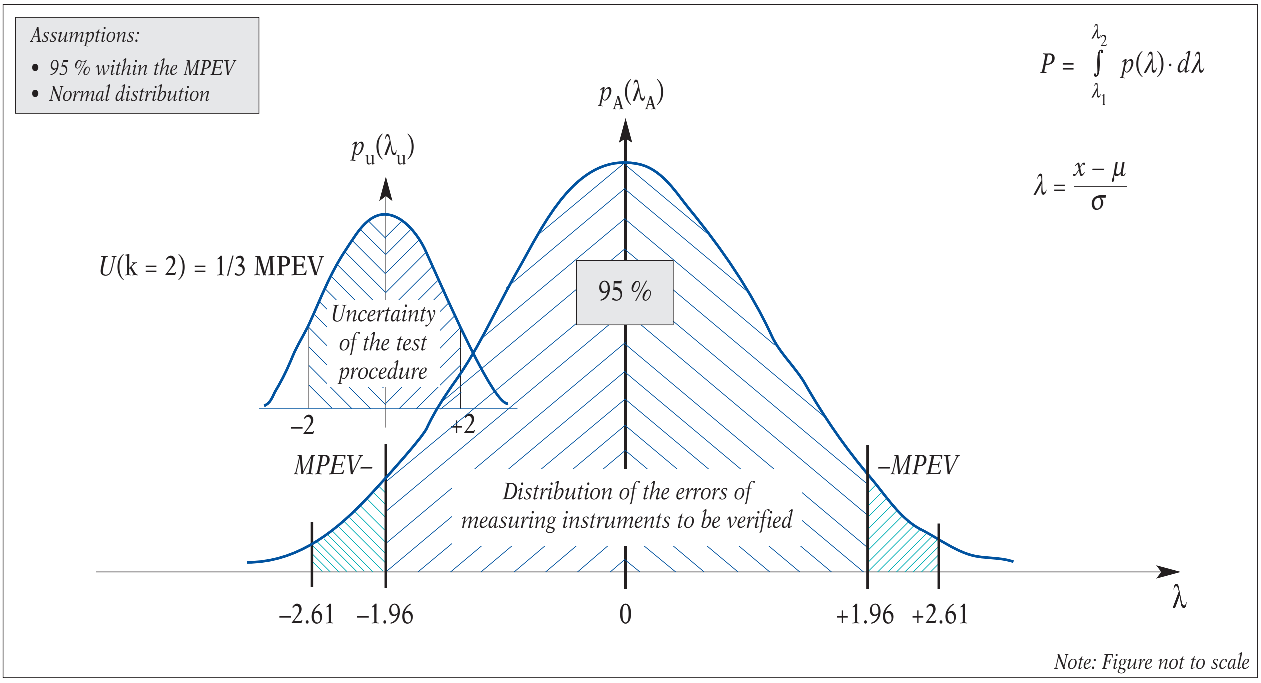

Fig. 4 Consideration of uncertainties of measurement in conformity decisions

The answers to these questions are illustrated by Example 4.

Example 4: Consequences of the measurement uncertainty in conformity assessment on a batch of instruments

The calculation will be based on the typical case of a unit-tested batch of instruments where the intrinsic measurement errors due to manufacturing variation more or less follow a normal distribution. This implies that 5 % of the instruments will in fact lie outside the error limits. In addition, it is assumed that the spread of values resulting from the uncertainties in the metrological test are normally distributed, and that the measurement uncertainty amounts to the maximum permissible value of U (k = 2) = 0.33 MPEV.

Figure 4 illustrates these conditions. If a measurement error is based on the (lower) error limit, combination of both distributions will result in the following:

(a) The expected proportion of "faulty" instruments which are assessed as indicating correctly will be less than 2 %;

(b) The probability that the mpe on verification will be exceeded by a factor of more than 1.33 is practically zero. (cf. Fig. 4).

The significance of statement (3) made in Example 4 has to be emphasized.

To reach the mpe in service an extra (reserve) tolerance is therefore available. It equals 66 % of the mpe on verification at minimum. Thus the effects of temporal drift and additional external influences on the measurement result may safely be compensated (cf. 4.3.1). This means even after prolonged use and with varying external influences, the risk for the user that the mpe in service is exceeded is practically zero.

The fact that, even in the worst case, the value of the mpe on verification is not exceeded by a factor of more than 1.33 facilitates conversion into other systems. An example is the situation where it is required that the sum of the measurement error and of the expanded measurement uncertainty must lie within given assessment limits.

5 Conclusions

5.1 Present situation

Due to the legal regulations to which verification is subjected, the user of a verified instrument may assume that during the validity period the instrument will indicate values within the mpe's in service. This is the case even if the measurement uncertainties are taken into consideration so that there is no shared risk. If the environmental conditions during use are the same as those prevailing during verification, the values can be expected to be even better than the mpe's on verification (probability 95 %). But in the worst case, for a small proportion of the instruments, they may be 1.33 times the mpe on verification. This value is significant for the user of an instrument which is outside the regulatory sphere, but who still has to prove traceability to national standards.

Verification comprises calibration and certification. These should comply with the international technical regulations, e.g. with ISO/IEC DIS 17025 [6]. For calculation or estimation of measurement uncertainties, the GUM [2] and EA-4/02 [3] are equally applicable. However, calibration is only part of the verification, and adaptations are required to take this into account. Some generalizations are also required for consumer protection reasons.

5.2 Further development

It should be remembered that the GUM guidelines concerning measurement uncertainties in legal metrology are incomplete. New instructions for calibration and testing including measurement uncertainty calculations have to be established and a future concept should include at least the following measures:

- integration in the uncertainty budget ("one-third uncertainty budget", presently being confined to the working standard) due to the testing procedure and the instrument under test during verification;
- definition of the mpe in service as the limit which must not be exceeded in the metrological evaluation for consumer protection reasons. The deviation extended by the measurement uncertainty (k = 2) should be less than the mpe.
- if someone is going to use a verified measuring instrument as a standard in accordance with the ISO 9000 series, they should be informed of the relationships between:
    - measurement uncertainty;
    - the mpe on verification; and
    - the mpe in service.

In the past, government bodies were not required to prove such transparency. Due to the increasing transfer of regulatory tasks to private institutions and manufacturers within the framework of international harmonization, government authorities are also required to meet uniform regulations. ■

References

[1] *International Vocabulary of Basic and General Terms in Metrology*, BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1993

[2] *Guide to the Expression of Uncertainty in Measurement*, BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, Corrected and reprinted, 1995

[3] EA-4/02, *Expression of the Uncertainty of Measurement in Calibration*, Ed. 1, European Cooperation for Accreditation of Laboratories, April 1997, (previously EAL-R2)

[4] ISO 8402, *Quality - Terms and Definitions*

[5] EN 45001, *General criteria for the operation of testing laboratories*, 1990

[6] ISO/IEC DIS 17025:1998 *General requirements for the technical competence of testing and calibration laboratories*

[7] EA-3/02, *The Expression of Uncertainty in Quantitative Testing*, Ed. 1, European Cooperation for Accreditation of Laboratories, August 1996, (previously EAL-G 23)

[8] ISO 14253-1: 1998, *Geometrical Product Specification (GPS) - Inspection by measurement of workpieces and measuring equipment*, Part 1: *Decision rules for proving conformance or nonconformance with specification*

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Note from the BIML: A "Secondary Guide" to the expression of measurement uncertainty in legal metrology is being developed as an application of the GUM. A working document prepared by Gérard Lagauterie, Sous-Direction de la Métrologie, France, was distributed at the TC 3 meeting held in June 1999, a report of which is published in this Bulletin. Several attending persons, including Dr. Sommer, participated in discussions. The continuation of this work project has been allocated to the recently established TC 3/SC 5 *Conformity Assessment*, under the joint responsibility of the USA and the BIML. ■