Treatment of Measurement Uncertainties in International and European Standards on Acoustics

Klaus Brinkmann
ISO/TC 43 Chairman
Sauerbruchstrasse, 31
D-38116 Braunschweig
GERMANY

Roger Higginson
CEN/TC 211 Chairman
Higginson Acoustics Ltd
9, Segbury Grove
Bracknell
BERKSHIRE RG12 9JL
UNITED KINGDOM

Leif Nielsen
ISO/TC 43 and CEN/TC 211 Secretariat
Danish Standards Associaton
Kollegievej, 6
DK-2920 Charlottenlund
DENMARK

This paper presents the adopted policy of the International and European standards committees ISO/TC 43 "Acoustics", ISO/TC 43/SC 1 "Noise" and CEN/TC 211 "Acoustics". It further discusses the recent experience with the implementation of these requirements in standards of these committees on acoustical noise measurement.

Cet article présente la politique adoptée par les comités de normalisation européens et international ISO/TC 43 «Acoustique», ISO/TC 43/SC 1 «Bruit» et CEN/TC 211 «Acoustique». De plus, il présente la récente expérience de mise en œuvre de ces exigences dans les normes de ces comités sur la mesure en acoustique.

National Metrology Institutes and calibration laboratories have, for several decades, evaluated the uncertainty of their measurement results and stated corresponding figures in calibration certificates as an indicator of accuracy and reliability. In the course of increasing cross-border co-operation, especially during the realization of the inner European market, best measurement capabilities of laboratories based on uncertainty estimations received more and more attention and became even an important marketing factor. It was then obvious that a common understanding on how to determine and to express measurement uncertainty was essential to make data reliable and comparable. These considerations led to an agreement on an internationally harmonized procedure for the evaluation of uncertainty which was issued in 1993 by six well recognized international organizations and today is known world-wide as the "Guide to the expression of uncertainty in measurement" (GUM).

Basically, it has already been recognized at an early stage that uncertainties of quantitative test results should be evaluated as well and that the principles of the GUM were equally applicable to all kind of measurements including those used by testing laboratories. Nevertheless, only exceptionally did those laboratories estimate and state their uncertainties in test reports. This was mainly due to a considerable lack of knowledge in this field. Moreover, a certain reluctance of customers was observed indicating that they did not really like to be confronted with the fact that test results are not "exact" per se.
This attitude, however, changed over the years when customers became aware that any kind of measurement results can only be reliably compared when their corresponding uncertainties are known and that, quite often, valid statements about the compliance of a product with specified limits can only be made if the uncertainty of test results is taken into account. This became especially relevant when manufacturers developed a vital interest to have test results for their products recognized internationally thus avoiding duplications of tests. As in calibration, a growing interest of customers can be predicted to select among competing testing laboratories the one which provides most reliable results at a reasonable price.

This imposed some pressure on testing laboratories which considerably increased when ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories, was first issued in 1999. Since then, this standard forms the basis for laboratory accreditation around the world. It requires that "testing laboratories shall have and shall apply procedures for estimating the uncertainty of measurement" and, moreover, that "when estimating the uncertainty of

measurement, all relevant uncertainty components which are of importance in a given situation shall be taken into account using appropriate methods of analysis".

It is still apparent, however, that testing laboratories often are not familiar with the uncertainty concept and may thus be unable to meet these requirements without further guidance. With some justification, they expect to receive information on the evaluation of measurement uncertainties from international or national standards. However, with some exceptions, standards generally do not yet provide this kind of guidance. Therefore, laboratory and accreditation organizations jointly approached the main international standardization bodies ISO and IEC some years ago expressing their concern about this situation and asking for more attention to be paid to this issue during the development of international standards specifying measurement methods.

In consequence of the above, respective discussions were initiated within relevant international Technical Committees on acoustics, such as IEC/TC 29 "Electroacoustics", ISO/TC 43 "Acoustics" and, especially, ISO/TC 43/SC 1 "Noise". The respective conclusions of these discussions taken by ISO/TC 43 and TC 43/SC 1 and recent experience with their implementation are presented in the following sections. A special section is devoted to the situation in the corresponding European Technical Committee which is CEN/TC 211 "Acoustics".

Policy of ISO/TC 43 "Acoustics" and TC 43/SC 1 "Noise" with respect to measurement uncertainty

First steps

The need to put more emphasis on the issue of measurement uncertainty when developing new or revised measurement standards was recognized by ISO/TC 43/SC 1 already in 1999. The following resolution was adopted:

"ISO/TC 43/SC 1 requests each of its Working Groups to consider the "Guide to the expression of uncertainty in measurement" in the preparation of documents and, if appropriate, include a statement of measurement uncertainty".

It appeared, however, that even among experts appointed to ISO Working Groups, sufficient knowledge about the proper treatment of measurement uncertainty in international standards was hardly available. With a few exceptions, the results remained unsatisfactory. It became obvious that some more information and direct guidance had to be provided on the principles of the GUM and its application to measurements in acoustics. For this reason, a brief technical seminar was held for all delegates to Working Group and Plenary meetings of TC 43 and its Subcommittes in Berlin in September 2003.

This seminar was attended by around 100 experts and was quite well accepted. Though it could not be the intention to assist Working Groups in their specific problems, the seminar certainly reduced existing aversion to approach the subject and submitted the right impression that the application of the GUM is less complex than it might have been suspected before.

A short policy paper was introduced and accepted with slight modifications at the following plenary meetings. It is considered as a pragmatic approach to the subject and since then forms the basis for the treatment of uncertainty in ISO Standards on measurement and prediction of sound. The paper is reproduced in full in the following section followed by additional interpretation of some selected aspects.

Treatment of measurement uncertainty in standards on acoustics (adopted policy paper, document ISO/TC 43 N 1023, June 2004)

1- If relevant, each standard shall contain a specific clause on measurement uncertainty in its main text. It shall contain the following statement:

«The uncertainty of results obtained from measurements according to this International Standard shall be evaluated, preferably in compliance with the GUM. If reported, the expanded uncertainty together with the corresponding coverage factor for a stated coverage probability of ...% (preferably 95 %) as defined in the GUM shall be given. Guidance on the determination of the expanded uncertainty is given in Annex yx.»

2- The GUM shall be added to the list of normative references.
3- In a clause dealing with test reports, it shall be stated that the reporting of measurement uncertainty is considered mandatory unless, in a particular case, a working group has good reasons for leaving it optional.
4- The annex on uncertainty should be structured as follows:

- general information;
- a functional relationship (model) that links all relevant input quantities to the quantity to be determined (measurand);
- an uncertainty budget in tabular form, containing the input quantities dominating the total uncertainty, their best estimates, the standard uncertainties associated with these values, the assumed probability distributions, the sensitivity coefficients derived from the model and the resulting contributions to the combined standard uncertainty;
- the calculation of the expanded uncertainty for the stated coverage probability.

Annex J of ISO 3745:2003-12-01 provides a useful example of this principle.

5- The evaluation of measurement uncertainty is the responsibility of each laboratory performing the measurement. Even if the requirements of the standard are fully met, the uncertainty of results from different laboratories may differ depending on the specific measurement conditions.

It is up to each working group to decide whether quantitive information on the various uncertainty contributions can be given or not and whether this information is considered to represent a typical situation or rather a worst case.

It is emphasized that a detailed uncertainty budget in accordance with the GUM will provide useful information on the

major uncertainty contributions and will enable the laboratory to improve certain measurement conditions in order to reduce the overall uncertainty, if requested.

6- If it appears during the preparation of a standard that sufficient knowledge is not yet available to fully apply the GUM while solid information on reproducibility data from interlaboratory comparisons is available, this information shall be given. A statement shall then be included in the main text that the expanded uncertainty for a stated coverage probability of 95 % shall be given as two times the standard deviation of reproducibility.
NB : If a coverage probability different from the preferred 95 % is chosen, this factor has to be adjusted accordingly.

This approach is, however, to be regarded as intermediate only and shall be replaced by the expression of uncertainty in conformity with the GUM in any future revision of the standard. Guidance on how the GUM may be principally applied, as described under item 4 above, shall be included in the standard already now."

Additional interpretation

Paragraph 1:

Each standard specifying a method for the measurement or prediction of sound, be it new or a revision of an existing standard, shall contain a clause on measurement uncertainty as given. It requests that the uncertainty has to be evaluated when the standardized method is applied. Preference is give to the GUM. However, in recognition of the fact that present knowledge might not always allow application of the GUM quantitatively, other methods of evaluation are permitted (see paragraph 6 below). It is further recognized that, in accordance with ISO/IEC 17025, the measurement uncertainty need not always be stated in test reports. However, if reported, some uniformity is needed. Therefore, the expanded measurement uncertainty together with the chosen coverage probability (preferably 95%) as specified in the GUM shall be stated.

Moreover, each standard shall contain an annex where the concept of the GUM is described in detail for the given application allowing a laboratory to apply these evaluation principles in cases where definite figures on the various uncertainty sources cannot be specified at the present stage.

Paragraph 2:

The text underlines the need to refer to the GUM when applying the given standard.

Paragraph 3:

See the interpretation remarks on paragraph 1.

Paragraph 4:

As further guidance to Working Groups, an outline of the contents of the uncertainty annex is given. It especially mentions the need to formulate a functional relationship describing the measurements and to establish an uncertainty budget preferably in tabular form.

A recently published standard developed in TC 43/SC 1, i.e. ISO 3745:2003, Acoustics – Determination of sound power levels of noise sources using sound pressure – Precision method for anechoic and hemi-anechoic rooms, is mentioned as providing a valuable example on how to structure and draft the uncertainty annex. This example is considered to be easily adaptable to other measurement standards in acoustics.

Paragraph 5:

It is emphasized that it is finally the responsibility of a testing laboratory to evaluate its uncertainty even if a standardized method is applied. There may always be certain deviations from the given method and, on the other hand, specific measurement conditions in a laboratory might be more favorable than generally allowed. The Working Group may decide whether it is appropriate to include figures in the uncertainty budget and whether, in the affirmative, such figures are to be considered as worst case or typical.
In any case, the attempt to evaluate the relevant sources of uncertainty according to the GUM is of great benefit for the laboratory since it allows detection of the main contributions to the overall uncertainty and may then lead to a reduction of the uncertainty if requested by the customer of the test.

Paragraph 6:

It is recognized that present knowledge may not always be sufficient to apply the GUM in each quantitative detail (see paragraph 1 above). On the other hand, reliable data from interlaboratory comparisons are sometimes available providing valid data on reproducibility which occurs if the method is applied by different laboratories. The adopted policy, therefore, allows proper use to be made of these data for statements of the measurement uncertainty in test reports as a pragmatic and intermediate step in order not to hinder the ongoing standardization process. However, the prerequisite for using such data is that solid data from intercomparisons using the specified method really exist and are not just estimated. Furthermore, it has always to be realized that measurement uncertainty based on reproducibility data may provide a too optimistic picture since not all uncertainty sources may have been become apparent in the interlaboratory comparisons.

Recent experience with the implementation of the TC 43 policy paper

Experience in a Working Group responsible for basic measurement standards on machinery noise

In a current revision of all the standards in the series ISO 3740-ISO 3747, Acoustics – Determination of sound power levels and sound energy levels of a noise source using measurements of sound pressure – the practice already adopted in ISO 3745:2003 mentioned above has been further developed. Most of the revised standards in the series are at present at the stage of 2nd Committee Draft. In this form, they each include a mandatory clause on measurement uncertainty, which states that:

1- Measurement uncertainties shall normally be evaluated in conformity with the GUM. However, the information necessary to achieve this is not at present available and guidance is given in an informative annex.
2- Standard deviations of reproducibility, relevant to each individual standard in the series, are given based on published laboratory intercomparisons.

3- The expanded measurement uncertainty for a coverage probability of 95% is then to be taken as two times the standard deviation of reproducibility, unless more specific knowledge is available.

In the informative annex to each standard in the series, a functional relationship is stated between the measurand (the sound power level or the sound energy level of the noise source) and all the known parameters, including the physical quantities and a number of input quantities which allow for variability in the test results (that is, the sources of measurement uncertainty). While most of these input quantities are known relevant to the various test procedures described in the series of standards, it is admitted that research could show that there are others. Moreover, the magnitudes and functional relationships of the input quantities are not known at present. The annex goes on to list in tabular form the kind of information which is required to evaluate the magnitudes of the sources of uncertainty, but because of the present lack of knowledge, there are no data in the table.

The aim of the ISO Working Group is to conduct extensive research in order to obtain the missing information, and then in a further future revision of all the standards in the series to include the information and so to comply fully with the requirements of the GUM at that time.

Observations from the Committee Secretariat

It is obvious that it was not until the establishment of the general policy paper, doc ISO/TC 43 N 1023, that most Working Groups and project leaders started taking sincere notice of the requirement for uncertainty statements. And because standards development is a relatively slow process, experience with the implications is still limited. Nevertheless, several reactions have been registered. Some first reactions were very opposing, arguing that, e.g. in relation to external noise measurement there are so many unknown influences that the establishment of an uncertainty budget is impossible. Other groups have - consciously or not - ignored the requirement, and, finally, a number of groups have accepted the requirement and tried to include appropriate uncertainty statements in their drafts. In all three cases, however, it is obvious that the new uncertainty requirements have caused delays in the finalization of documents, some even to the extent that they have not yet been finalized after the introduction of the uncertainty policy document.

A great number of documents are still under development in Working Groups and have not yet been seen by a broader audience, and it is going to be interesting to see whether they will contain appropriate uncertainty statements when they reach the stage of the first circulation to the member countries.

Despite these problems it is acknowledged that, basically, at least attempts to implement the uncertainty requirements in the existing drafts from ISO/TC 43 and SC 1 - and thus also CEN/TC 211 (see chapter 4) are now being made relatively readily. It is obvious, however, that this would never have been accomplished without the personal efforts of the chairman of ISO/TC 43 and SC 1, first in getting the general policy paper established, and subsequently in making constructive comments on all relevant drafts which have been circulated, and even having direct discussions with some project leaders.

Formally, the basic criterion for approval of international standards is the approval of the member countries. It is therefore worth noting that national comments on drafts also - slowly - seem to start requesting uncertainty statements where they are missing. On the other hand it is surprising that there seems to be no pressure or assistance from the top level or the Central Secretariat of ISO to include appropriate uncertainty statements so at the moment the general success of the need for uncertainty statements in international standards depends fully on the initiatives and efforts in the individual committees.

Recent results as seen by the Committee Chairman

Since the adoption of the TC 43 policy paper in September 2003, 35 documents specifying various methods for sound measurement and prediction were prepared by different Working Groups and circulated to ISO Member Bodies for comments. Nearly 90% of them were at a rather early stage of development (Committee Drafts). The others have already reached the stage of Draft International Standards. Among the Committee Drafts, nearly 30% of them were issued twice in the given period, the second time following the consideration of the comments received on the first version.

With one exception, all documents issued contain at least some information on measurement uncertainty. In nearly 70% of the documents, considerable efforts were made to adapt the concluded policy to the specified measurement procedure. For the remaining 30%, different approaches were followed. To some extent, the latter is surprising since the policy paper gives specific advice on how to draft the respective clauses and provides a valuable example of the structure and partly even of the wording of which could be copied.

A major problem still appears to be the expression of a functional relationship between the quantity to be measured (measurand) and those input quantities which have to be considered when determining the measurand and its corresponding uncertainty. Such an equation is unavoidable when the uncertainty is to be evaluated according to the rules of the GUM. Sometimes, the reluctance of Working Groups to formulate such a relationship is hardly understandable since all the needed information is included in the document at least in a verbal form. Moreover, at least one example how to present the information in a mathematical form is available and was offered to all Working Groups for consideration.

Another observation of a technical nature is that apparently only little solid data on the expected contributions from the various uncertainty sources mentioned in the documents exist. To some extent, this is astonishing since by far the largest percentage of the presently developed documents constitute revisions of existing standards having been in use for at least a couple of years. In cases where data are included, they sometimes appear to be rather optimistic estimates. Here is much room for further investigations. From the view of the ongoing standardization process, however, this lack of knowledge does not really hinder the progress of developing documents since the adopted policy merely requires specification of the concept of uncertainty evaluation

according to the GUM, leaving it to the users of a certain standard to develop their own empirical knowledge to derive the total uncertainty of a measurement.

Another apparent problem, though essentially of an editorial nature is the terminology related to uncertainty. Terms such as "random and systematic errors", "level of confidence", "accuracy" in quantitative statements, etc. should be avoided but are still in common use. Based on the same background, the former rules of "error propagation" are often applied. This seems to be a question of education and will certainly quickly be overcome.

On each of the circulated documents, the Committee Chairman submitted detailed comments mostly offering specific proposals for amendments. Even minor editorial points were raised to avoid the risk of poor examples being copied. In the majority of documents however, some technical changes are necessary. In most cases, the given advice is well accepted and efforts are visible to improve the respective sections. Comments of an editorial nature have usually been immediately incorporated in the next version.

It was noted that comments received from ISO Member Bodies on these documents touch the subject of uncertainty only in exceptional cases indicating that knowledge in this area is not yet very widespread at the national level.

Policy of CEN/TC 211

At its first meeting in 1989, CEN/TC 211 adopted a resolution in principle to develop most of its standards through the corresponding international committees, ISO/TC 43 and ISO/TC 43/SC 1. Since that time, this policy has been followed and all its standards with one exception have been adopted by parallel voting, in conformity with the Vienna Treaty. While CEN/TC 211 has not taken a resolution specifically on policy in relation to statements of measurement uncertainty, it has by adoption of all the relevant ISO standards taken a de facto position of following the ISO practice. This remains the position to date.

Conclusions

ISO TC 43 "Acoustics" and its Subcommittee 1 "Noise" recently adopted a specific policy on the treatment of measurement uncertainty in newly developed or revised standards dealing with measurement and prediction of sound. This policy could not be expected to be fully implemented immediately. Considerable improvements were, however, achieved in less than two years since its adoption. Most of the Working Groups concerned are quite eager to meet the new challenge and it is certain that further progress will be made if more acceptable documents become available. A Working Group having once reached consensus on a certain concept and wording will quickly transfer this to other documents under their responsibility. However, considering the large number of approximately 80 sound measurements standards issued by TC 43 and its SC 1 so far, it will certainly take some years before each of these standards is updated with respect to measurement uncertainty.

The efforts of the standardization bodies should be considered as a contribution towards a more transparent description of noise measurement results facilitating their assessment. It is hoped that they will be acknowledged by the customers. ■