INTERNATIONAL STANDARD

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Acoustics — Measurement of sound insulation in buildings and of building elements —

Part 2:
Determination, verification and application of precision data

Acoustique — Mesurage de l'isolation acoustique des immeubles et des éléments de construction —

Partie 2: Détermination, vérification et application des données de fidélité

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 140-2 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

This second edition cancels and replaces the first edition (ISO 140-2:1978), of which it constitutes a technical revision.

ISO 140 consists of the following parts, under the general title *Acoustics — Measurement of sound insulation in buildings and of building elements*:

— *Part 1: Requirements for laboratories*

— *Part 2: Determination, verification and application of precision data*

— *Part 3: Laboratory measurements of airborne sound insulation of building elements*

— *Part 4: Field measurements of airborne sound insulation between rooms*

— *Part 5: Field measurements of airborne sound insulation of facade elements and facades*

— *Part 6: Laboratory measurements of impact sound insulation of floors*

— *Part 7: Field measurements of impact sound insulation of floors*

— *Part 8: Laboratory measurements of the reduction of transmitted impact noise by floor coverings on a standard floor*

— *Part 9: Laboratory measurement of room-to-room airborne sound insulation of a suspended ceiling with a plenum above it*

— *Part 10: Laboratory measurement of airborne sound insulation of small building elements*

Annex A forms an integral part of this part of ISO 140. Annexes B and C are for information only.

Introduction

It is not possible to specify completely the construction of laboratory test facilities or the sound field conditions obtained. Therefore some details of the test facilities and procedures in ISO 140-3 to ISO 140-9 are left to the choice of the operator. This, together with the statistical character of sound fields within rooms, leads to uncertainties in the results due to non-systematic (random) and systematic influences.

Random influences can be determined by repeated independent measurements under essentially similar conditions.

Systematic influences (for example, size and shape of test rooms, mounting conditions of the test specimen, calibration of measuring equipment) cannot be determined by a simple procedure. Generally, comparison measurements in different test facilities and knowledge of the random uncertainties under these conditions are necessary in order to assess the systematic influences.

In agreement with modern statistical methods, the concepts of repeatability and reproducibility obtained from complete test results are used in this part of ISO 140, rather than variances of the individual quantities that make up the test result. Repeatability values and reproducibility values offer a simple means of stating the precision of a test method and of measurements carried out according to the test method.

The repeatability and reproducibility are two extremes, the first measuring the minimum and the second the maximum variability in test results. Other intermediate measures of variability between these two extremes are conceivable, such as repetition of tests within a laboratory over longer time intervals, or by different operators, or including the effects of recalibration, but these are not considered in this part of ISO 140.

If, in a particular situation, some intermediate measure should be needed, it must be clearly defined, together with the circumstances under which it applies and the method by which it should be determined.

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Acoustics — Measurement of sound insulation in buildings and of building elements —

Part 2:
Determination, verification and application of precision data

1 Scope

This part of ISO 140 specifies procedures for assessing the uncertainty in the acoustical measurements described in ISO 140-3 to ISO 140-9 due to random and systematic influences.

It gives guidelines for

— determination of the repeatability value r and the reproducibility value R;

— verification of repeatability values r and reproducibility values R for different measurement arrangements in one laboratory and for comparisons between different laboratories;

— application of repeatability values r and reproducibility values R in practice.

Tentative repeatability values and reproducibility values of the test methods according to ISO 140-3, ISO 140-4 and ISO 140-6 to ISO 140-8 are given in annex A.

NOTE 1 At present no data are available for ISO 140-5 and ISO 140-9.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 140. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 140 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 140-3:1978, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 3: Laboratory measurements of airborne sound insulation of building elements.*

ISO 140-4:1978, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 4: Field measurements of airborne sound insulation between rooms.*

ISO 140-5:1978, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 5: Field measurements of airborne sound insulation of facade elements and facades.*

ISO 140-6:1978, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 6: Laboratory measurements of impact sound insulation of floors.*

ISO 140-7:1978, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 7: Field measurements of impact sound insulation of floors.*

ISO 140-8:1978, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 8: Laboratory measurements of the reduction of transmitted impact noise by floor coverings on a standard floor.*

ISO 140-9:1985, *Acoustics — Measurements of sound insulation in buildings and of building elements — Part 9: Laboratory measurement of room-to-room airborne sound insulation of a suspended ceiling with a plenum above it.*

ISO 717-1:1982, *Acoustics — Rating of sound insulation in buildings and of building elements —*

Part 1: Airborne sound insulation in buildings and of interior building elements.

ISO 717-2:1982, *Acoustics — Rating of sound insulation in buildings and of building elements — Part 2: Impact sound insulation.*

ISO 717-3:1982, *Acoustics — Rating of sound insulation in buildings and of building elements — Part 3: Airborne sound insulation of facade elements and facades.*

ISO 5725:1986, *Precision of test methods — Determination of repeatability and reproducibility for a standard test method by inter-laboratory tests.*

3 Definitions

For the purposes of this part of ISO 140, the following definitions apply. Whenever applicable, they are equivalent to those given in ISO 3534, ISO 5725 and in the International vocabulary of basic and general terms in metrology.

3.1 test result, y: The final value obtained in a single frequency band by following the complete set of instructions given in a test method.

NOTE 2 A set of test results is obtained since a determination is carried out in several frequency bands.

3.2 true value, u: The value characterizing a quantity perfectly defined under the conditions existing when that quantity is considered. For practical purposes, it is the arithmetic mean of test results obtained by a large number of laboratories. Consequently, such a practical true value is associated with the particular test method.

3.3 accuracy of the mean: The closeness of agreement between the true value and the mean result obtained by applying the test method a very large number of times.

The smaller the systematic part of the experimental errors affecting the results, the more accurate is the test method.

3.4 precision: The closeness of agreement between mutually independent test results obtained under prescribed conditions.

NOTES

3 Precision depends only on the distribution of random errors and does not relate to the true value or the specified value.

4 Repeatability and reproducibility are concepts of precision. See ISO 5725.

3.5 arithmetic mean, $\bar{y}$: The arithmetic mean of test results, given by the equation

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i \qquad \dots (1)$$

where n is the number of test results y_i.

3.6 sample variance, s^2: The sum of squares of the deviations from the arithmetic mean of test results, divided by the number of degrees of freedom. In the simple case of n consecutive (ungrouped) test results, the sample variance is given by the equation

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{n} (y_i - \bar{y})^2 \qquad \dots (2)$$

3.7 standard deviation, s: The square root of the sample variance.

3.8 number of degrees of freedom, ν: The number of independent terms contained in the expression for the sample variance. In the simple case of n consecutive (ungrouped) test results

$$\nu = n - 1 \qquad \dots (3)$$

3.9 repeatability: The closeness of agreement between mutually independent test results obtained under repeatability conditions.

NOTE 5 Repeatability can depend on the type of construction (homogeneity, resonance, etc.).

3.10 repeatability conditions: Conditions where mutually independent test results are obtained with the same method on identical test material in the same laboratory with the same equipment by the same operator within short intervals of time.

3.11 repeatability standard deviation, s_r: The standard deviation of test results obtained under repeatability conditions. It is a parameter of dispersion of the distribution of test results under repeatability conditions.

NOTE 6 Similarly, the repeatability variance and repeatability coefficient of variation could be defined and used as parameters of dispersion of test results under repeatability conditions.

3.12 repeatability value, r: The value below which the absolute difference between two single test results obtained under repeatability conditions may be expected to lie with a probability of 95 %.

3.13 reproducibility: The closeness of agreement between test results obtained under reproducibility conditions.

NOTE 7 Reproducibility can depend on the type of construction (homogeneity, resonance, etc.).

3.14 reproducibility conditions: Conditions where test results are obtained with the same method on identical test material in different laboratories with different operators using different equipment.

3.15 reproducibility standard deviation, s_R: The standard deviation of test results obtained under reproducibility conditions. It is a parameter of dispersion of the distribution of test results under reproducibility conditions.

NOTE 8 Similarly, the reproducibility variance and reproducibility coefficient of variation could be defined and used as parameters of dispersion of test results under reproducibility conditions.

3.16 reproducibility value, R: Value below which the absolute difference between two single test results obtained under reproducibility conditions may be expected to lie with a probability of 95 %.

3.17 confidence interval (two-sided): An interval between two estimated limits within which a statistical parameter is expected to be found with a probability of 95 %.

3.18 critical difference, CrD_{95}: In statistical terminology, the repeatability values and the reproducibility values are critical differences at the 95 % probability level valid for two single test results obtained under repeatability or reproducibility conditions.

NOTE 9 When verifying the repeatability value r and the reproducibility value R, it is mostly the practice to carry out more than two tests and a critical difference corresponding to the average of such tests will be needed. Critical differences valid under such modified conditions can be derived from the repeatability value r and the reproducibility value R and are given in 4.6, 4.7 and clause 5.

4 Determination of the repeatability value r and the reproducibility value R by inter-laboratory tests

The repeatability value r and the reproducibility value R of a test method shall be determined by an inter-laboratory test, taking into account the considerations given in this clause and using various kinds of test specimens. These determinations should be repeated from time to time, especially whenever changes are made in the test method.

4.1 General

The general concept and the procedure for determining the repeatability value r and reproducibility value R are given in ISO 5725. The repeatability value r and the reproducibility value R are given by

$$r = 2{,}8\sqrt{s_r^2} \qquad \ldots (4)$$

$$R = 2{,}8\sqrt{s_R^2} = 2{,}8\sqrt{s_r^2 + s_L^2} \qquad \ldots (5)$$

where

s_r^2 is the mean of the within-laboratory variances taken over all participating laboratories (weighted according to the number of valid results returned by the participating laboratories; see ISO 5725:1986, 11.6.1);

s_L^2 is the between-laboratory variance taken over all participating laboratories;

s_R^2 is the reproducibility variance.

The factor 2,8 comes from the fact that the repeatability value r and the reproducibility value R apply to differences between two single results (see ISO 5725:1986, 5.5).

NOTE 10 The estimators s_r^2 and s_L^2 are used since true values σ_r^2 and σ_L^2 are not known. The repeatability value r and reproducibility value R as determined from equations (4) and (5) are therefore estimates of these quantities.

The repeatability value r and reproducibility value R are determined from the test results of inter-laboratory tests. As many operators and laboratories as possible should participate in such inter-laboratory tests in order to obtain reliable test results. The proper organization and evaluation of inter-laboratory tests are complicated and require special knowledge of the statistical background. They are dealt with in ISO 5725. In view of the considerable expense involved, the instructions given in ISO 5725 shall be followed in every detail in order to avoid failure of the test. Additional rules to be observed for use in the field of building acoustics are given below.

The organization of an inter-laboratory test involves statistical problems which should be entrusted to a statistical expert. The task of this expert is

— to assist in designing the inter-laboratory test;

— to analyse the data and to eliminate outliers by various statistical tests;

— to calculate the repeatability values r and reproducibility values R of the test method from the valid data.

When the final repeatability values r and the reproducibility values R have been established by the means of an inter-laboratory test, it is possible to verify that they correspond to a probability of 95 %, as required by the definitions, by means of the data from which they have been computed. While not strictly necessary, this verification may serve as a check for the correctness of the calculations and the quality of the data. The procedures for this are described in 4.6 and 4.7.

Since the repeatability values r and the reproducibility values R are calculated from the estimators s_r^2 and s_L^2, they will themselves be estimates, subject to errors. The probability levels associated with the repeatability values r and the reproducibility values R will therefore not be exactly 95 % but only of the order of 95 %. Nevertheless, differences larger than the repeatability values r or the reproducibility values R shall be considered suspect.

4.2 Test conditions

The acoustical test conditions for determining the repeatability value r and reproducibility value R shall correspond to the conditions given in the relevant parts of ISO 140. The test specimen shall not be remounted between repeated measurements.

4.2.1 Each laboratory shall use its normal test procedure when participating in an inter-laboratory test. The criteria which affect the repeatability of the measurement (see the relevant parts of ISO 140) shall be carefully observed. No deviations from the test procedure laid down shall occur but, carrying out the test by repeating the measurements several times, the parameters left open in the test procedure shall be represented as well as possible. In particular, the set of microphone positions and source positions over which averaging is carried out in one measurement shall be selected anew, more or less randomly, for each repeated measurement.

NOTE 11 Very strictly defined test procedures tend to improve the repeatability of a specific laboratory but increase the possibility of a bias on all test results of that laboratory.

Before the inter-laboratory test is started, each participating laboratory shall report the exact details of its test procedure.

4.2.2 Additional requirements for carrying out inter-laboratory tests for the test specimen chosen shall be laid down in detail. This refers in particular to the following items:

a) quantities to be measured and reported, rules for rounding numbers;

b) number of replicate tests required;

c) calibration of test equipment;

d) mounting and sealing conditions of the test specimen, and curing time where appropriate.

4.3 Number of participating laboratories

Considering the frequency dependence of the quantities measured in building acoustics (comparable to the "level of the test property" of ISO 5725:1986, 5.2), the number of laboratories should, from a statistical point of view, be at least $p = 8$, but it is preferable to exceed this number in order to reduce the number of replicate tests required. The number n of test results in each laboratory should be so chosen that $p(n-1) \geqslant 35$. In addition, at least five test results are needed for each laboratory. The test results obtained shall not be preselected in any way by the participating laboratories before they are reported.

4.4 Requirements for stating the test results of inter-laboratory tests

In order to simplify the evaluation of test results reported, it is strongly desirable to supply form-sheet(s) to be filled in by the participants. For the statistical analysis it is important to report special observations and/or any irregularities observed during the tests.

4.5 Choice of test specimen

The kind of test specimen to be used for an inter-laboratory test depends not only on the quantity to be tested (i.e. airborne sound reduction index, normalized impact sound pressure level, etc.) but specifically on the mounting and testing conditions for which the repeatability values and the reproducibility values are to be obtained (e.g. walls, floors, windows). The effect of ageing on the test specimen shall be also be considered.

The choice of test specimen also depends on practical considerations and influences the course of action to be taken in case of failure of the inter-laboratory test. Generally speaking, three different plans depending on the type of test method and/or on the type of specimen may be appropriate (see 4.5.1 to 4.5.3).

4.5.1 Use of a single test specimen (same material circulated among participants)

For checking the test procedure and the test facilities in different laboratories, ideally, the same test specimen should be used by all participants in the inter-laboratory test and checked again by the first laboratory at the end of the inter-laboratory test.

In building acoustics, this procedure will often not be feasible due to the long period of time required, the risk of damage or change of the test specimen, and different sizes of test openings. However, the variability resulting from the use of more than one test specimen is avoided and the reproducibility values R thus obtained are characteristic for the test facility and test procedure alone.

4.5.2 Use of several test specimens taken from a production lot (nominally identical material exchangeable among participants)

In contrast to the procedure described in 4.5.1, all participants of the inter-laboratory test receive nominally identical test specimens, i.e. coming from the same production lot or of identical design and constructed by one manufacturer. This enables testing in parallel and reduces the risk of damage or of change due to the influence of time. However, the variability among the test specimens due to their heterogeneity is then inseparable from the error variability of the test procedure, and forms an inherent part of the reproducibility. For this reason it may be advantageous to check all test specimens for homogeneity with more precision at one laboratory before the inter-laboratory test and possibly also after its completion.

4.5.3 Use of several test specimens constructed *in situ* (nominally identical material not exchangeable among participants)

When the test specimens cannot be prefabricated and readily transported, they shall be constructed *in situ* by each participant according to close specifications. In this case the variability among the test specimens due to their heterogeneity is even larger than for test specimens according to 4.5.2.

4.6 Verification of repeatability values r as part of the inter-laboratory test

As stated in 4.3, at least $p = 8$ laboratories should deliver at least $n = 5$ complete test results. Then, for each frequency band, $n(n-1)/2$ absolute differences between single results y_i and y_k obtained within the laboratory can be calculated and compared with the critical difference $\mathrm{CrD}_{95}(|y_i - y_k|) = r$ of that frequency band. For all p laboratories and q frequencies, a total of $qpn(n-1)/2$ comparisons will be obtained, and it should be expected that the corresponding critical differences are exceeded in not more than 5 % of the cases. For example, with $p = 8$, $n = 5$ and $q = 16$ there will be 1 280 comparisons, of which not more than about 64 should exceed the critical differences. Conversely, the number of times the critical differences are exceeded divided by the total number of absolute differences will give the observed probability in the inter-laboratory test which should be at (or near) the 95 % level.

4.7 Verification of reproducibility values R as part of the inter-laboratory test

If $p = 8$ laboratories having taken part in an inter-laboratory test had made just one determination each, then $p(p-1)/2$ absolute differences between results y_a and y_b of any two laboratories a and b could be compared with the critical difference $\mathrm{CrD}_{95}(|y_a - y_b|) = R$ in each frequency band. For $q = 16$ frequency bands there will be $qp(p-1)/2 = 448$ comparisons, and it should be expected that the corresponding critical differences are exceeded in not more than 5 % of the cases, i.e. not more than about 22 times. Again, the number of times the critical differences are exceeded divided by the total number of absolute differences will give the observed probability in the inter-laboratory test, which should be at (or near) the 95 % level.

However, as stated in 4.3, at least $n = 5$ determinations should be made by each laboratory and a critical difference corresponding to the average of the test results of each laboratory used.

The critical difference for comparing averages is

$$\mathrm{CrD}_{95}(|\bar{y}_a - \bar{y}_b|) = \sqrt{R^2 - r^2\left(1 - \frac{1}{2n_a} - \frac{1}{2n_b}\right)} \qquad \ldots (6)$$

where

r and R have been determined in the inter-laboratory test;

$\bar{y}_a$ and $\bar{y}_b$ are the averages of n_a and n_b determinations made in laboratories a and b, respectively.

If $n_a = n_b = n$, which will usually be the case, then

$$\mathrm{CrD}_{95}(|\bar{y}_a - \bar{y}_b|) = \sqrt{R^2 - r^2\left(1 - \frac{1}{n}\right)} \qquad \ldots (7)$$

For $n = 1$, this reduces to the reproducibility value R as expected.

The critical differences thus calculated for each frequency band are compared with the observed differences of the averages in that frequency band. Since for each laboratory there is one average, the number of possible comparisons is the same as above, namely $qp(p-1)/2$.

4.8 Repeatability values r and reproducibility values R

Repeatability values r and reproducibility values R obtained from inter-laboratory tests according to 4.1 to 4.5 will be given in the appropriate parts of ISO 140 when they are revised. For the time being, tentative repeatability values and tentative reproducibility values are listed in table A.1, table A.2 and table A.3.

NOTE 12 The repeatability values r and the reproducibility values R for test results expressed in single-number quantities are given in annex B .