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Mechanical vibration — Uncertainty of the measurement and evaluation of human exposure to vibration

Vibrations mécaniques — Incertitude de mesure et évaluation de l'exposition humaine aux vibrations

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 4, *Human exposure to mechanical vibration and shock*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document takes the form of a guide and describes how to deal with the uncertainty of vibration quantities associated with human exposure to vibrations.

The uncertainty arises from various sources. These uncertainties need to be distinguished from errors, such as when using measuring instruments or selecting the measurement strategy, which may falsify the measurand. Errors are not considered in this guide.

Calculations of measurement uncertainty are meaningful and valid only if all significant mistakes have been identified.

This document is intended to be used as a reference document for other standards. Examples of the application of the individual methods in practical situations are provided in the annexes. These examples are related to hand-arm vibration but the principles also apply for whole-body vibration.

Mechanical vibration — Uncertainty of the measurement and evaluation of human exposure to vibration

1 Scope

This document specifies methods for determining the uncertainty of the measurement and evaluation of human exposure to vibration. It applies to measurements of vibration quantities (measurands), calculated following a relevant measurement model on the basis of directly measured values, to evaluate

a) human exposure to hand-transmitted vibration at the workplace,

b) vibration emission of hand-held and hand-guided machinery in a laboratory setting,

c) human exposure to whole-body vibration at the workplace, and

d) whole-body vibration emission of vehicles.

Examples of the application of the individual methods in practical situations are provided in the annexes.

In this document a measurement error is defined as the difference between a measured and a reference quantity value.

In this document "uncertainty" does not include errors that result from bad measurement strategies, faulty use of measurement equipment or other mistakes.

2 Normative references

The following document is referred to in the text in such a way that some or all of it's content constitutes requirements 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.

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 99 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
input quantity in a measurement model
input quantity
X
quantity that must be measured, or a quantity, the value of which can be otherwise obtained, in order to calculate a measured quantity value of a measurand

EXAMPLE When evaluating the daily vibration exposure, vibration magnitude and exposure time are input quantities of a measurement model.

Note 1 to entry: An input quantity in a measurement model is often an output quantity of a measuring system.

Note 2 to entry: Indications, corrections and influence quantities can be input quantities in a measurement model.

Note 3 to entry: An estimated value for X is x.

[SOURCE: ISO/IEC Guide 99:2007, 2.50, modified — example adapted and Note 3 added]

3.2
output quantity in a measurement model
output quantity
Y
quantity, the measured value of which is calculated using the values of input quantities in a measurement model

$$Y = f(X_1, X_2, ...) \quad (1)$$

Note 1 to entry: An estimated value for Y is y.

[SOURCE: ISO/IEC Guide 99:2007, 2.51, modified — Formula and Note 1 added]

3.3
arithmetic mean value
$\bar{x}$
best estimated value for the expected value of the individual measured values when N independent observations $x_{i,1}, x_{i,2}, \ldots, x_{i,N}$ are available for the *input quantity* (3.1), X_i:

$$\bar{x}_i = \frac{1}{N} \sum_{k=1}^{N} x_{i,k} \quad (2)$$

Note 1 to entry: The arithmetic mean value of the output quantity for N independent observations is

$$\bar{y} = \frac{1}{N} \sum_{k=1}^{N} y_k \quad (3)$$

3.4
variance
s^2
measure for the scattering of the measured values when N individual measured values are available for the variable X_i:

$$s_i^2 = \frac{1}{N-1} \sum_{k=1}^{N} \left(x_{i,k} - \bar{x}_i\right)^2 \quad (4)$$

Note 1 to entry: This Formula produces an estimated value for the variance of the *measured values*.

Note 2 to entry: An estimated value for the variance of the *mean value* is

$$s^2(\overline{x_i}) = \frac{s_i^{\ 2}}{N} \tag{5}$$

Note 3 to entry: The variance of the mean value is always smaller than the variance of the measured values.

3.5
standard deviation
s
positive square root of the *variance* (3.4)

Note 1 to entry: The standard deviation of the individual *measured values* is therefore

$$s_i = \sqrt{\frac{1}{N-1}\sum_{k=1}^{N}\left(x_{i,k} - \overline{x_i}\right)^2}\ s_i \tag{6}$$

The standard deviation of the measured values is a measure for the scattering of the measured values in a sample (measurement series) around their (arithmetic) mean value. It is also referred to as s_{n-1} in standards to determine vibration emission values of machines (see Annex A).

Note 2 to entry: The standard deviation of the *mean value* is

$$s(\overline{x_i}) = \sqrt{\frac{1}{N(N-1)}\sum_{k=1}^{N}\left(x_{i,k} - \overline{x_i}\right)^2} \tag{7}$$

The standard deviation of the mean value is a measure for the accuracy of repeated measurements. Formula (7) is used when Type A evaluation is applied (see A.2).

3.6
sensitivity coefficient
c_i
partial derivative of the *output quantity* (3.2) according to X_i at the location of the estimated values of the *input quantities* (3.1):

$$c_i = \left.\frac{\partial f}{\partial X_i}\right|_{x_1,\ldots,x_N} \tag{8}$$

Note 1 to entry: If the output quantity has a linear relation to the input quantity, c_i is a constant that can have any greater or lesser value. The X_i relation can also be selected in the model so that $c_i = 1$.

3.7
uncertainty
parameter assigned to the result of a measurement or calculation which identifies the scattering of the values that can sensibly be assigned to the measured or calculated variable

Note 1 to entry: The uncertainty does not necessarily have to be a standard deviation.

3.8
standard uncertainty
u
uncertainty (3.7) of the result of a measurement or calculation expressed as a *standard deviation* (3.5)

Note 1 to entry: The standard uncertainty $u(x)$ of a variable x has the same unit as x. The relative standard uncertainty $u(x)/(x)$ is dimensionless.

3.9
combined standard uncertainty
u_c
standard uncertainty (3.7) of a result *y* that is obtained from *L* values of other variables, X_i

Note 1 to entry: The combined standard uncertainty is equal to the positive square root of a sum of terms, whereby the terms are variances or co-variances of these other variables X_i, weighted according to the sensitivity coefficients c_i.

For a mathematical model of the measurand $Y = f(X_i)$ with uncorrelated input quantities X_i, the following applies in the first approximation:

$$u_c(y) = \sqrt{\sum_{i=1}^{L} {c_i}^2 u^2(x_i)} \quad (9)$$

The standard uncertainties $u(x_i)$ can be determined according to two types of evaluation (Type A and Type B evaluation, see ISO/IEC Guide 98-3).

3.10
coverage factor
k
factor by which the *combined standard uncertainty* (3.9), u_c, is multiplied to obtain the expanded uncertainty *U*

3.11
coverage interval
interval containing the set of true quantity values of a measurand with a stated probability, based on the information available

Note 1 to entry: A coverage interval does not need to be centred on the chosen measured quantity value (see ISO/IEC Guide 98-3:2008/Suppl.1).

Note 2 to entry: A coverage interval should not be termed “confidence interval” to avoid confusion with the statistical concept (see ISO/IEC Guide 98-3:2008, 6.2.2).

Note 3 to entry: A coverage interval can be derived from an expanded measurement uncertainty (see ISO/IEC Guide 98-3:2008, 2.3.5).

[SOURCE: ISO/IEC Guide 99:2007, 2.36]

3.12
coverage probability
probability that the set of true quantity values of a measurand is contained within a specified coverage interval

Note 1 to entry: This definition pertains to the uncertainty approach as presented in the GUM.

Note 2 to entry: The coverage probability is also termed “level of confidence” in the GUM.

[SOURCE: ISO/IEC Guide 99:2007, 2.37]

3.13
expanded uncertainty
U
product of the *coverage factor* (3.10), *k* and the *combined standard uncertainty* (3.9), u_c, which describes the range $y \pm U$ around the result *y*, which can be expected to comprise a majority of the distribution of those values that can be reasonably attributed to the result:

$$U = ku_c \quad (10)$$

Note 1 to entry: In EN 12096, the expanded uncertainty is indicated by the letter *K*. It is used in the determination of the measured vibration value *a* and also indicates the dispersion in the production of batches of machines. The value *K*, however, does not include all uncertainty components.

3.14
test subject
person exposed to the vibration that is determined by a measuring body

Note 1 to entry: The test subject is also referred to as the operator, operating personnel or exposed person.

3.15
measuring personnel
persons responsible for performing the measurements, in particular managing the measuring instruments

3.16
measuring body
organizational unit that is responsible for conducting the measurements, in particular managing the measuring instruments and personnel

3.17
reproducibility conditions
conditions where test results are obtained with the same method on identical test items in different measuring bodies by different *measuring personnel* (3.15) using different equipment

Note 1 to entry: The method can define operating conditions, type and number of test subjects, or measurement environments, for example.

Note 2 to entry: The measurement time or the measurement object can vary depending on the problem or aim of the measurement; for example, if the measurement object is a workpiece that changes during measurement or if the influence of aging of a machine is to be determined.

[SOURCE: ISO 5725-1:1994, 3.18, modified — "Laboratory" replaced by "measuring body", "operator" replaced by "measuring personnel"]

3.18
in-situ conditions
reproducibility conditions (3.17) in the same measurement environment

Note 1 to entry: The measurement environment is influenced, for example, by the ambient temperature which can influence the conditions of the measuring instrumentation and measurement object.

3.19
repeatability conditions
conditions where independent test results are obtained with the same method on identical test items in the same *measuring body* (3.16) and measurement environment by the same member of *measuring personnel* (3.15) using the same equipment within short intervals of time

[SOURCE: ISO 5725-1:1994, 3.14, modified — "Laboratory" replaced by "measuring body and measurement environment", "operator" replaced by "member of measuring personnel" and Note 1 deleted]

3.20
reproducibility standard deviation
measuring body standard deviation
σ_L
standard deviation (3.5) of results obtained under *reproducibility conditions* (3.17)

Note 1 to entry: The measuring body standard deviation is also referred to as the measuring body or laboratory deviation or scattering.

Note 2 to entry: Depending on the measuring method, it is not always possible to create the same conditions. For example, ISO 20643 requires three different test subjects for vibration emission measurements. The reproducibility standard deviation then includes the test subject standard deviation.

Note 3 to entry: The measuring body standard deviation principally consists of the standard deviation of the measuring instrument and the standard deviation that results from the measurement strategy that is used. It therefore also includes interpretations of the measurement standard, for example with regard to the points of the transducer coupling and locations of the measurement point.

3.21
in-situ standard deviation
σ_s
standard deviation of results obtained under *in-situ conditions* (3.18)

3.22
repeatability standard deviation
σ_r
standard deviation of results obtained under *repeatability conditions* (3.19)

Note 1 to entry: According to ISO 5349-2, at least three individual measurements should be made.

3.23
interlaboratory test
series of measurements performed by different laboratories or measuring bodies under *reproducibility conditions* (3.17)

Note 1 to entry: Interlaboratory tests (sometimes referred to as "Round robin tests") can have very different objectives. For example, to verify a measurement method, to determine measurement uncertainties or to benchmark for a particular measuring body.

3.24
specified value
vibration value that is specified in a technical rule or required by law or otherwise that is to be complied with

Note 1 to entry: Depending on the context, the specified value is referred to as the limit value, action value, guidance value or threshold limit value.

3.25
production standard deviation
standard deviation (3.5) of results obtained under the same conditions for different new products of the same type of device or machine in a series

Note 1 to entry: With the exception of the product to be measured (for example machine or vehicle), all other conditions (measuring instrument, measuring body, measuring personnel, test subjects, measuring conditions and the measurement method and, if relevant, also the in-situ conditions) are the same.

Note 2 to entry: The production standard deviation is also referred to as the product scattering in EN 12096. However, the product scattering can also include the deviation due to aging.

3.26
test subject standard deviation
standard deviation (3.5) of results obtained under the same conditions, but with different *test subjects* (3.14)

Note 1 to entry: With the exception of the test subject (for example machine user or vehicle driver, all other conditions (machine, vehicle, measuring instrument, measuring body, measuring personnel, measuring conditions and the measurement method and, if relevant, also the in-situ conditions) are the same.

Note 2 to entry: If the individual measurements are not performed promptly, changes can occur in the same test subject, for example change of mass, change of behaviour or improved skill.

3.27
uncertainty budget
<for a measurement or calibration> statement summarizing the estimation of the *uncertainty* (3.7) components that contributes to the *uncertainty* (3.7) of a result of a measurement

Note 1 to entry: The uncertainty of the result of the measurement is unambiguous only when the measurement procedure (including the measurement object, measurand, measurement method and conditions) is defined.

Note 2 to entry: The term “budget” is used for the assignment of numerical values to the uncertainty components and their combination and expansion, based on the measurement procedure, measurement conditions and assumptions.

[SOURCE: ISO 14253-2:2011, 3.9]

3.28
measurand
quantity intended to be measured

EXAMPLE 1 The potential difference between the terminals of a battery may decrease when using a voltmeter with a significant internal conductance to perform the measurement. The open-circuit potential difference can be calculated from the internal resistances of the battery and the voltmeter.

EXAMPLE 2 The length of a steel rod in equilibrium with the ambient temperature of 23 °C will be different from the length at the specified temperature of 20 °C, which is the measurand. In this case, a correction is necessary.

Note 1 to entry: The specification of a measurand requires knowledge of the kind of quantity, description of the state of the phenomenon, body, or substance carrying the quantity, including any relevant component, and the chemical entities involved.

Note 2 to entry: In the second edition of the VIM and in IEC 60050-300:2001, the measurand is defined as the ‘quantity subject to measurement’.

Note 3 to entry: The measurement, including the measuring system and the conditions under which the measurement is carried out, might change the phenomenon, body, or substance such that the quantity being measured may differ from the measurand as defined. In this case, adequate correction is necessary.

[SOURCE: ISO/IEC Guide 99:2007, 2.3, modified — Note 4 to entry deleted]

4 Considerations regarding the uncertainty of vibration measurements

4.1 Measurement objectives and fixed parameters

The consideration of measurement uncertainty shall begin with a clear understanding of the objectives of the measurements. The measurement objectives will define those parameters that are fixed and those that contribute to the uncertainty evaluation. For example, our objectives may be any of the following:

a) to obtain an in-use vibration value for a particular task for a particular tool or vehicle, as used by a particular operator;

b) to obtain a typical in-use vibration value for a particular task for that particular tool or vehicle (used by any worker);

c) to obtain a typical in-use vibration value for a particular task for that type of tool or vehicle.

NOTE The vibration value can be a vibration emission value, a vibration immission value or a vibration exposure value.

Other objectives may also be possible, but in each case, the fixed parameters are different, and will affect how the measurement is planned so that measurement uncertainties can be determined. For the three scenarios above, there are two key variations, relating to the machine and to the machine operator, which are associated with each objective.

— To achieve objective a), measurements for the specified task on the identified tool or vehicle with the same operator are sufficient. The measurements do not require the assessment of differences between operators or machines, they are both fixed.

— To achieve objective b), measurements for the specified task on the identified tool or vehicle are needed with a number of machine operators. The measurements require consideration of differences between operators, while the machine is fixed.

— To achieve objective c), measurements for the specified task of a number of samples of the tool or vehicle types used by a number of machine operators are needed. The measurements require consideration of differences between operators and machines.

These examples, only consider two variable parameters. It may be necessary to consider other variables, such as machine configuration, materials, inserted tools, machine models, ages, maintenance, road conditions. Table 1 provides more examples of factors that may need to be accounted for when planning a measurement strategy. The examples also only consider vibration magnitude evaluation; in many cases the measurement will be of vibration exposure, in which case consideration of exposure time uncertainties will be required.

4.2 Types of uncertainties

It is useful to define three distinct types of uncertainty relating to vibration measurements.

a) Measurement equipment uncertainty: Uncertainties related to the system selected for the measurement: transducer calibration, mounting, instrumentation, signal processing and data handling.

b) Measurement procedure uncertainty: Uncertainties related to

   1) decisions that have to be made when performing a measurement, such as the selection of: transducer locations, measurement periods, test subjects, work tasks, and

   2) the skill and experience of the person performing the measurements.

Uncertainties need to be distinguished from errors. Examples of typical errors are listed in Annex C

NOTE Measurement equipment uncertainty and measurement procedure uncertainty are representing the laboratory uncertainty. Performing measurements according to a standardised procedure usually limits the measurement uncertainty.

c) Measurement restrictions uncertainty: Depending on the objectives, uncertainties may result from the limited access to a representative sample of measurement environments (usually issues outside the measurer's control). These could include restrictions on the

   1) availability of work sites, tasks or machines,

   2) environmental conditions (temperature, noise humidity) during measurements,

   3) machine operator physical characteristics (e.g. height, mass and strength), and

   4) machine operator skill, experience and behaviour.

4.3 Measurement instrumentation uncertainty sources

Measurement uncertainty connected with the measurement instrumentation is dealt with in ISO 8041-1.

5 Evaluation of the uncertainty

5.1 Evaluation of the uncertainty through mathematical modelling

For various reasons, the aim is to draw up a detailed uncertainty budget based on a mathematical model of the evaluation of measurement, including interferences. One reason is that a budget of this kind can be used to determine the most important uncertainty components and, if applicable, reduce them. Furthermore, the uncertainty determined through such a mathematical model reflects the concrete conditions that were actually present when determining the measurand. That means the uncertainty is individually adapted to the measurand. This clause provides instructions for determining such uncertainty budgets.

Examples of models for measuring procedures are provided in Annex B.

The functional relation f between input and output quantity is often not known. In such cases, it can be assumed that the individual, uncorrelated variables X_i have a linear relation to the output quantity and the associated sensitivity coefficients, c_i = 1. The following is one possible formulation of this assumption:

$$Y = \overline{y} + \sum_i X_i \tag{11}$$

In Formula (11), the input quantities X_i are random numbers that are obtained from a distribution with a given standard deviation, s_i and the mean value $\overline{x}_i = 0$. If no other information is available, it can be assumed that the input quantities have a normal (Gaussian) distribution. Formula (9) for the combined standard uncertainty, then simplifies to

$$u_{\mathrm{c}}(y) = \sqrt{\sum_{i=1}^{L} u^2(x_i)} \tag{12}$$

The terms of Formula (12) can be determined according to two types of evaluation (Type A and Type B evaluation, see ISO/IEC Guide 98-3).

The term that describes the variance for repeated measurements in Formula (12) is determined according to the Type A method. For n repeated measurements, the variance is described by the standard deviation of the mean value $s(\overline{x}_i)$. For measurement series with less than about 30 repeated measurements, the standard deviation of the mean value should still be corrected using the Bayes term.

$$s_{\mathrm{corr}}(\overline{x}_i) = \sqrt{\frac{n-1}{n-3}}\, s(\overline{x}_i) \tag{13}$$

The uncertainty in this case is equal to $u(x_{\mathrm{repeat}}) = s_{\mathrm{corr}}$.

All other uncertainties $u(x_i)$ can be calculated according to the Type B method. Two cases frequently occur.

a) If an estimated value and its uncertainty $u(x_i)$ are known (e.g. from a calibration report), this uncertainty is used. A normal distribution is assumed.

b) If it is known that the estimated value is between two values, a rectangular distribution can be assumed. For a symmetrical distribution of the input quantities around the mean value, i.e.

   $X_i = \overline{x}_i \pm a$, the uncertainty is

$$u(x_i) = \frac{a}{\sqrt{3}} \tag{14}$$

Besides this analytical approach to the combined standard uncertainty via Formula (9), a numerical approach can also be selected (see ISO/IEC Guide 98-3:2008/Suppl.1). If it is assumed that the input quantities are uncorrelated random numbers, the uncertainty of the output quantity can be determined using a Monte Carlo calculation. In this case, in contrast to Formula (9), it is possible to use any distributions and standard deviations of any magnitude.

5.2 Determination of the uncertainty from interlaboratory tests

If the uncertainty is only limited to the reproducibility standard deviation, σ_L and the repeatability standard deviation, σ_r, the combined standard uncertainty u_c from an interlaboratory test can be stated as standard deviation σ_R.

$$u_c = \sigma_R = \sqrt{\sigma_L^2 + \sigma_r^2} \tag{15}$$

The fundamental concept and the method for determining these standard deviations are described in ISO 5725-1 and ISO 5725-2. Both standard deviations are determined in interlaboratory tests, in which as many measuring bodies as possible should participate, in order to gain reliable results. The reproducibility and repeatability standard deviations describe the combined standard uncertainty linked to a method. This combined standard uncertainty is associated with all results that were determined using the same specified method. It can therefore also be used as estimated value for an in-situ standard deviation.

The method for which the reproducibility or repeatability standard deviation is to be determined shall be described exactly. Each participating measuring body shall apply the method in such a way that in the repeated measurements as many of the possibilities are covered as possible. For example, in many situations the vibration transducers should be recoupled for each repetition.

The measurement results shall not be subject to any preselection by the measuring bodies.

NOTE The choice of test object for an interlaboratory test not only depends on the measurand to be determined, but also on the specified boundary conditions, such as setup and operating conditions. Practical aspects can also be considered. Ideally, the same test object can be used by all measuring bodies, which is examined by the first measuring body for possible changes at the end of the interlaboratory test ("round robin test"). However, it is also possible that all participants receive nominally identical test objects, for example from one production batch. In this case, a consistency test can be conducted to investigate factors such as ageing or maintenance before and possibly also after the interlaboratory test.

5.3 Determination (estimation) of uncertainties from field measurements

If the uncertainty of a measurement and the mathematical model is not known, uncertainties determined from other investigations can be applied to the task under consideration as being indicative. In some cases such values are specified in standards for example for hand-held motor-operated tools (see series IEC 60745) and transportable motor-operated electric tools (see series IEC 61029), a constant value is specified for the expanded uncertainty, to which an emission measurement is assigned. EN 12096 specifies an estimated value for the expanded uncertainty for the production standard deviation.

If estimating uncertainty from comparative data, the accuracy of the uncertainty estimate is largely dependent on how many conditions are the same between the new measurements under consideration and the comparison data set used for the estimation. Influencing factors are listed in Table 1. Table 1 illustrates possible considerations for two example cases where comparison data are being considered. A detailed example with values can be found in Annex A.

Table 1 illustrates factors which may be significant. However, many other conditions can be included in the analysis, such as the age and condition of the machine and its engine or power supply, and inserted tool or attachments used, the workpiece or vehicle loading, measurement environment, measuring personnel, machine operators and measuring instrument.

NOTE The referred vibration quantities are usually the vibration accelerations directly measured at the interfaces between the human body and a tool, a machine, a vehicle, or a workpiece using a method defined in an ISO standard, or those derived or calculated using the accelerations defined in the standard. The general concepts and methods described in this document can also be optionally applicable to help analyse the uncertainty of the vibration quantities or biodynamic responses measured at or on the human body.

Table 1 — Illustration of influencing factors for uncertainty data

	Examples	
	Hand-arm vibration	**Whole-body vibration**
Example case:	*Uncertainty of vibration measurement of an angle grinder cutting steel pipe in a workplace*	*Uncertainty of vibration measurement of a forklift truck in a warehouse*
Influencing factors	Is the comparison data set based on measurement:	
Measurands are identical. i.e.: the measured values are evaluated according to the same specification.	— in accordance with ISO 5349-2, for example using the W_h frequency weighting	— in accordance with ISO 2631-1, for example using W_k & W_d frequency weightings
The measurements to determine the measurand are transferable.	— on machine handles, at the centre of the gripping zone during periods of representative cutting	— on the vehicle seat, during periods of representative driving
The measured objects (machines) should be identical as far as possible in terms of vibration generation, size and coupling to the environment.	— grinder of identical make and model or similar specification, size, power and cutting wheel	— vehicle of identical make and model or similar specification, load capacity and power — suspension seat of identical make and model or similar performance category
The work processes of the measured objects are transferable.	— during cutting (rather than grinding) a similar material	— driving on warehouse style road surface at speeds similar to those in a warehouse
The machine operator, measurement duration and number of measurements for determining the measured values are comparable.	— with similar forces, posture, hand position and cutting rates	— handling similar loads with similar travel distances and loading rates
The environment	— temperature, location (inside, outside), weather conditions	— weather conditions, surface conditions

6 Presentation of results

Vibration quantities shall be given with their physical units, such as m/s^2.

The uncertainty information shall include

a) an uncertainty value, reported either using the physical unit of the output quantity (e.g. as m/s^2) or as a percentage,

b) the coverage factor of the uncertainty value,

c) any relevant additional information, such as use of non-Gaussian distributions.

The uncertainty value of the measurand (the expanded uncertainty) is dependent on the combined standard uncertainty u_c determined according to Clause 5 and on the selected one- or two-sided coverage probability, taking into account the coverage factor k required by the application.

A one-sided coverage probability is considered when it is necessary to ensure that the expected value y of the measurand does not exceed a limit value y_{max} (or does not fall below a limit value y_{min}). For a p, the expected value is only above the upper limit value (or below the lower limit value) with a probability of $1 - p$.

A two-sided coverage probability is assumed, if the expected value y of the measurand for a coverage probability, p, has to lie within a symmetrical interval around the mean value of the measured values. In the case of a distribution density function assumed to be symmetrical, the expected value y only lies above the upper interval limit or below the lower interval limit with a probability of $1 - p/2$ in each case.

The coverage factor, k, is e.g. 1,0 or 1,3 etc., depending on the desired coverage probability for two-sided and for one-sided tests, see Table 2.

EXAMPLE For a typical measurement of a hand-held drilling tool a coverage probability of 95 % is commonly used, which results in a coverage factor of 1,6 for one-sided tests and a coverage factor of 2,0 for two-sided tests.

For the statistical background see Annex D.

Table 2 — Coverage factor for different coverage probabilities during one-sided and two-sided tests with normal distribution

Coverage factor (rounded) k	Coverage probability, p for two-sided tests %	Coverage probability, p for one-sided tests %
1,0	68	84
1,3	80	90
1,6	90	95
2,0	95	97,5

The measurement result shall be stated as follows:

a) For a two-sided test:

$$Y = \hat{y} \pm U = \hat{y} \pm k u_c \quad (16)$$

where

Y is the measurand;

$\hat{y}$ is the best estimated value determination on the basis of measurements;

U is the expanded uncertainty, see Formula (10).

EXAMPLE For a measured value of 12,5 m/s² and a determined combined standard uncertainty of 0,9 m/s² in a two-sided test at a selected coverage probability of 95 %, the following result is obtained:

$$a_{hw} = (12,5 \pm 1,8)\ \mathrm{m/s^2}$$

Thus, the expanded uncertainty is U = 1,8 m/s² with the coverage factor, k = 2 (see Table 2).

b) For a one-sided test (see also 7.2):

— If the aim is to comply with a specified value:

$$Y = \hat{y} + U = \hat{y} + k u_c \quad (17)$$

— If the aim is to exceed a specified value:

$$Y = \hat{y} - U = \hat{y} - ku_c \quad (18)$$

NOTE The above instructions apply to a positive specified value.

EXAMPLE For a measured (positive) value of 12,5 m/s² and a determined combined standard uncertainty of 0,9 m/s² in a one-sided test at a selected coverage probability of 95 %, the following result is obtained according to Formula (17):

$$a_{hw} = (12{,}5 \pm 1{,}44)\ m/s^2$$

Thus the expanded uncertainty is U = 1,44 m/s² with the coverage factor, k = 1,6 (see Table 2). A specified value of 13,94 m/s² would be met with a coverage probability of 95 %.

The complete measurement result therefore consists of the estimated value for the measurand and its expanded measurement uncertainty.

NOTE Indication of the best estimated value $\hat{y}$ without an expanded uncertainty, as was previously typical practice, is equivalent to a coverage probability of just 50 %.

7 Use of uncertainties

7.1 General

Whether and how uncertainty is used can be defined by statutory provisions or contractual agreements. The use of uncertainty is determined by the purpose of the measurement.

7.2 Use of uncertainties in comparisons

When comparing results with specified values, uncertainty plays a significant role, for example when evaluating measurement results. The use of uncertainty is typically required by a standard or other technical rule or regulation. A distinction can be made between the following cases with regard to deciding whether the result determined according to a specified method, taking into account the expanded uncertainty U, complies with a specified value Y_{req} (for example a limit value), whereby the uncertainty is used as an increased or reduced allowance.

— The decision “specified value complied with” is reached reliably when the result plus uncertainty does not exceed the specified value:

$$y + U \leq Y_{req} \quad (19)$$

— The decision “Specified value exceeded” is reached reliably when the result minus uncertainty exceed the specified value:

$$y - U > Y_{req} \quad (20)$$

NOTE The above instructions apply to a positive specified value.

Annex A
(informative)

Uncertainty in the measurement of hand-arm vibration at the workplace — Example for determination of the measurement uncertainty of the vibration exposure during task-based measurements according to ISO 5349-2

A.1 Introduction

This annex is concerned with the uncertainty of the measurement of hand-arm vibration at the workplace using mathematical modelling according to 5.1. Results from interlaboratory tests are also applied in this case (see 5.2).

Uncertainty based on empirical values according to 5.3 can be applied for an initial rough estimation from the illustrative values according to EN 12096 for measured values between 2,5 m/s^2 and 5 m/s^2 to be 50 % and for measured values > 5 m/s^2 to be 40 %. Emission measurement standards frequently only give conventions for estimating the expanded uncertainty; these conventions are designated as K values.

A.2 Principles of the calculation

A.2.1 General

The uncertainty when recording the longer-term typical vibration exposure is derived based on the random sample linked to the measurement (limited measurement duration). In order to reduce this uncertainty, a particularly careful work analysis in conjunction with very careful measurements or a very large amount of samples is necessary, depending on the measurement strategy chosen. Sometimes a full-shift measurement strategy can be a feasible way of reducing measurement uncertainty arising from limited measurement duration.

The mathematical model for the measurands corresponds to Formula (12). According to this, the following Formula applies to the combined uncertainty (total uncertainty, result of the uncertainty budget) u_c:

$$u_c \sqrt{\sum_{i=1}^{L} u^2(x_i)} \qquad \text{(A.1)}$$

A.2.2 Influencing factors

The state of knowledge concerning the precise extent of uncertainty is limited, which means only illustrative or estimated values can be indicated for measurements at the workplace. The values presented in Table A.1 are for illustration only, to provide information for the examples provided in this Annex.

Table A.1 — Example values for the measurement uncertainty components

<table>
<tr><th rowspan="3">i</th><th rowspan="3" colspan="3">Components $u(x_i)$ of the measurement uncertainty</th><th colspan="10">Relative uncertainty[e] u/x</th></tr>
<tr><th colspan="2">Rotary hammers[a]</th><th colspan="2">Chainsaws[b]</th><th colspan="2">Rotary hammers[c]</th><th colspan="2">Jigsaws[c]</th><th colspan="2">Grinders[c]</th></tr>
<tr><th>Range ± %</th><th>$u(x_i)$[e]</th><th>Range ± %</th><th>u_c[e]</th><th>± %</th><th>u_M[e]</th><th>± %</th><th>u_M[e]</th><th>± %</th><th>u_M[e]</th></tr>
<tr><td rowspan="2">1</td><td>Measuring instrument[d] for laboratory application</td><td rowspan="4">Measuring body standard deviation</td><td rowspan="4">$u_M = u(x_1, x_2, x_3)$</td><td>8,2 to 13</td><td>0,075</td><td rowspan="6">17 to 33</td><td rowspan="6">0,098 to 0,191</td><td rowspan="4">21,3</td><td rowspan="4">0,123</td><td rowspan="4">16,1</td><td rowspan="4">0,093</td><td rowspan="4">54,0</td><td rowspan="4">0,312</td></tr>
<tr><td>Measuring instrument[d] for field application</td><td>12,6 to 26</td><td>0,152</td></tr>
<tr><td>2</td><td>Transducer coupling (without mechanical filter)</td><td>5</td><td>0,029</td></tr>
<tr><td>3</td><td>Transducer position (measurement point)</td><td>30</td><td>0,173</td></tr>
<tr><td>4</td><td colspan="3">Repeatability standard deviation of one test subject (user)</td><td>(8)</td><td>(0,046)</td><td colspan="6">$u(x_4)_a$ according to Type A evaluation</td></tr>
<tr><td>5</td><td colspan="3">Test subject standard deviation</td><td>15</td><td>0,087</td><td colspan="6">—</td></tr>
<tr><td>6</td><td colspan="3">Production standard deviation</td><td>8</td><td>0,046</td><td colspan="8">—</td></tr>
</table>

[a] Values for rotary hammers except $u(x_1)$ from BAuA Report[20].

[b] Example values.

[c] From interlaboratory test "BGIA-Report"[21].

[d] From ISO 8041-1.

[e] All values u are relative uncertainty values.

A.2.3 Uncertainty under repeatability conditions (Type A evaluation)

A.2.3.1 Examining the repeatability conditions (measurement conditions)

In the task-based measurement strategy, the uncertainty of results when recording the typical vibration exposure depends on the uncertainty $u(x_4)_a$ of the frequency-weighted accelerations determined for the individual activities as well as the uncertainty $u(x_4)_t$ of the corresponding duration. The time sections shall be divided so that they apply for the repeatability conditions.

According to ISO 5349-2 at least three measurements are necessary for every individual activity m. The scattering of the measured values yields the standard uncertainty, $u(x_4)_{a,m}$ to be considered for the corresponding activity m:

$$u(x_4)_{a,m} = \sqrt{\frac{1}{I(I-1)} \sum_{i=1}^{I} \left(a_{\text{hv}\,i,m} - \overline{a_{\text{hv},m}} \right)^2} \quad \text{(A.2)}$$

where

$\overline{a_{\mathrm{hv},m}}$ is the arithmetic mean value of I measured vibration total value of frequency-weighted accelerations of activity m, i.e. $\overline{a_{\mathrm{hv},m}} = \frac{1}{I}\sum_{i=1}^{I} a_{\mathrm{hv}\,i,m}$;

I is the number of vibration measurement values for the activity m.

The standard uncertainty $u(x_4)_{t,m}$ for determination of the duration T_m of the activity m can be estimated or calculated from several time measurements $T_{j,m}$ as follows:

$$u(x_4)_{t,m} = \sqrt{\frac{1}{J(J-1)}\sum_{j=1}^{J}\left(T_{j,m} - \overline{T_m}\right)^2} \quad \text{(A.3)}$$

where

$\overline{T_m}$ is the average duration of activity m from the individual time measurements $T_{j,m}$;

J is the number of time measurements.

NOTE Often, the determination of the exposure duration is mostly based on rough estimations.

A.2.3.2 Checking the repeatability conditions (measurement conditions)

Depending on the measurement task, the suitable measurement strategies according to ISO 5349-2:2001, Annex E, shall be applied. The main sources of uncertainty that are caused by the activity (for example unbalance of a grinding disc, fluctuations in the output or coupling forces) shall be recorded and documented, if possible. If necessary, the number of repeated measurements shall be increased until the following criterion for the coefficient of variation C_v is complied with:

The number n of measurements shall be increased until C_v is less than 0,15.

The coefficient of variation C_v of a measurement series (of the operational state or of the partial activity to be recorded) is the ratio of the standard deviation s_{n-1} to the mean value $\overline{a_{\mathrm{hv}}}$ of the measurement series under repeatability conditions:

$$C_v = \frac{s_{n-1}}{\overline{a_{\mathrm{hv}}}} \quad \text{(A.4)}$$

where the standard deviation s_{n-1} of the measured values $a_{\mathrm{hv}\,i}$ is analogue with Formula (6).

$$s_{n-1} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(a_{\mathrm{hv}\,i} - \overline{a_{\mathrm{hv}}}\right)^2} \quad \text{(A.5)}$$

where

$\overline{a_{\mathrm{hv}}}$ mean value of the measurement series in m/s^2;

n number of measured values (measurements of a measurement series).

A.2.3.3 Example

The measurement series in Table A.2 of an impact drill consists of 5 repeated measurements that were tested with the same test subject under the same operating conditions.

Table A.2 — Example of a measurement series

Measurement	a_{hv} m/s^2
1	12,5
2	13,1
3	13,2
4	12,5
5	10

This produces the following values:

Mean value: $\overline{a_{hv}}$ = 12,26 m/s^2

Standard deviation: s_{n-1} = 1,31 m/s^2

Standard deviation of the mean value: $u(x_4)_a$ = 0,58 m/s^2

Coefficient of variation: C_v = 0,11

A.2.4 Uncertainty of the measuring instruments (Type B evaluation)

When using measuring instruments that satisfy the accuracy requirements of ISO 8041-1, the standard uncertainties $u(x_1)$ listed in Table A.1 can apply to the measuring instruments. These standard uncertainties are based on an estimation with the tolerance limits according to ISO 8041-1 and apply to determination of the energy-equivalent frequency-weighted acceleration. When determining other measurands, such as peak values, larger uncertainties are to be expected. Likewise, measuring instruments that do not correspond to ISO 8041-1 can have higher uncertainties.

NOTE Details of this estimation are provided in ISO 8041-1.

A.2.5 Uncertainty owing to the choice of measuring points and coupling (Type B evaluation)

Particularly in the case of hand-arm vibration, the position of the measuring point has a large effect on the measurement result. The uncertainties indicated in the emission measurement standards of the relevant instrument family can be used as an initial approximation. If no uncertainties are indicated in the relevant measurement standards, the values from Table A.1 can be used as illustration for $u(x_2)$ and $u(x_3)$.

The acceleration transducers shall be coupled without contact resonances. Guidelines on the correct coupling are given in the measurement standards. In practice, errors can occur here, which make a measurement uncertainty consideration impossible and are hence not discussed in this standard. Examples of typical errors are listed in Annex C.

A.2.6 Uncertainty due to the influence of the measuring body (measuring body scattering according to Type B evaluation)

The uncertainty of the measuring bodies results from the uncertainty of the measuring equipment (such as measuring instrument and calibrator) and its regular inspection and, to a large extent, from the experience and qualification of the persons performing the measurements.

Accredited measuring bodies that fulfil the requirements of ISO/IEC 17025 have a quality management system (QM system) and hence validate compliance with the requirements. The value u_M from Table A.1 can be only used if there are no systematic deviations and the quality requirements are fulfilled.

NOTE 1 The measuring body scattering essentially comprises the uncertainties of the measuring instrument, the coupling and the transducer position (see A.2.4 and A.2.5).

The uncertainty owing to the measuring body scattering is currently about ±35 % even with experienced measuring bodies with QM system. It is recommended that this important uncertainty be reduced by participation in interlaboratory tests.

NOTE 2 According to ISO 5349-2:2001, Clause 8, the uncertainty when determining $A(8)$ is often high (20 % to 40 %).

A.2.7 Transferability of the results to comparable workplaces (Type B evaluation)

A.2.7.1 General

If the purpose of the measurement is not the determination of the vibration exposure on a certain test subject or a workplace, but the determination of the vibration exposure that is representative of a certain machine or work task, then the uncertainties associated with the machine user (test subject) and production corresponding to Formula (A.1) shall be added for the total uncertainty (result of the uncertainty budget).

For economic reasons, the measurements are predominantly made with random samples with only one test subject and one machine. The components of the measurement uncertainty $u(x_5)$ and $u(x_6)$ shall then be estimated.

A.2.7.2 Uncertainty due to the influence of the test subject (Type B evaluation)

According to ISO 5349-2:2001, 7.3, the measurements shall be conducted with at least three different test subjects. The arithmetical mean of these measurements shall be indicated as the result; the standard deviation should also be noted.

A.2.7.3 Uncertainty due to production and aging of the measurement objects (Type B evaluation)

The production standard deviation depends to a large extent on the product. The indication of the K value in the operating instructions of the relevant machines and devices provides an illustration.

There is currently very little knowledge about the aging effect. Lower vibration can therefore result from a performance decline due to aging. However, the vibration can also increase due to worn bearings. Higher vibration due to aging of the rubber damping elements has also been observed in vibration damping systems. This effect can be several hundred percent in the case of poorly maintained machines. The value $u(x_6)$ indicated in Table A.1 for the production standard deviation applies for new or nearly new machines and devices.

A.3 Example for calculation of the daily vibration exposure and the measurement uncertainty for task-based measurements

A.3.1 Step 1: Work analysis

The vibration exposures for a window fitter's daily task of installing windows are determined in the example. The vibration exposure is generated by means of an impact drill and a hand milling machine. The impact drill is used for placing dowels for 10 min to 15 min and the same time is needed for drilling metal brackets. The groove milling machine is used for 40 min to 60 min.

A.3.2 Step 2: Selecting the measurement strategy

The measurements are conducted according to ISO 5349-2:2001, E.2.2, with the measurement duration the time the machine is actually in use. Work breaks are included in the recording.

A.3.3 Step 3: Calculation and presentation of the results and the repeatability deviation (practical example according to Type A evaluation)

The work cycles of the impact drill are measured separately for drilling into the wall (with impact action) and into metal (without impact action). Depending on the work cycle, five repeated measurements are conducted with two different test subjects. The mean value and the standard deviation of the mean value according to Formula (A.2) are determined from the measured values (see Table A.3).

Table A.3 — Mean value and standard deviation of the mean value

Acceleration in m/s²

m	**Machine** (activity m)	**Test subject 1**		**Test subject 2**	
		$\overline{a_{\text{hv},m}}$	$u(x_4)_a$	$\overline{a_{\text{hv},m}}$	$u(x_4)_a$
1	Impact drill (wall)	12,3	±0,6	13,0	±0,7
2	Impact drill (metal)	4,3	±0,7	5,5	±0,9
3	Milling machine	2,4	±0,2	3,0	±0,4

In case of measurement series with fewer than about 30 repeated measurements, the standard deviation of the mean value should be corrected with the Bayes term.

$$u(x_i)_{\text{corr}} = \sqrt{\frac{n-1}{n-3}}\, u(x_i) \tag{A.6}$$

This produces the corrected values according to Table A.4 for the n = 5 individual measurements per test subject and work cycle.

Table A.4 — Value corrected with the Bayes term

Standard uncertainty $u(x_4)_a$ **of the mean value from Table A.3** m/s²	**Bayes term for** n = 5	$u(x_4)_{a\ \text{corr}}$ m/s²
0,2	1,41	0,28
0,4	1,41	0,56
0,6	1,41	0,85
0,7	1,41	0,99
0,9	1,41	1,27

The mean values and corrected standard deviations of the mean value under repeatability conditions (repeatability standard uncertainties) are indicated in Table A.5.

NOTE 1 In this example it is assumed that the observations during the conducted measurements revealed that there was no significant risk of incorrect measurements.

The scattering shows a reproducibility of the repeated measurements. The coefficient of variation according to A.2.3.2 is complied with. Depending on the problem, the mean value of the relevant test subject or the total mean value shall be used.

NOTE 2 If the mean values of the individual test subjects are far apart, measurements with further test subjects are recommended. If the exposure is also used for other test subjects, use of the higher mean value is recommended.

Table A.5 — Mean value and corrected standard deviation of the mean value

Acceleration in m/s^2

m	**Machine** (activity m)	**Test subject 1**		**Test subject 2**	
		$\overline{a}_{\text{hv},m}$	$u(x_4)_a$	$\overline{a}_{\text{hv},m}$	$u(x_4)_a$
1	Impact drill (wall)	12,3	0,85 (0,069)[a]	13,0	0,99 (0,076)[a]
2	Impact drill (metal)	4,3	0,99 (0,230)[a]	5,5	1,27 (0,231)[a]
3	Milling machine	2,4	0,28 (0,117)[a]	3,0	0,56 (0,187)[a]

[a] The values in brackets are the relative values without unit.

A.3.4 Step 4 and all other steps according to Type B evaluation

A.3.4.1 General

The consideration of the further uncertainty components depends on the aim of the measurement or the further use of the measurement results.

The uncertainties according to Table A.1 shall be considered for the following cases.

— The measurement results are only used for evaluating the measured workplace (working device, operator and operating conditions are identical).

NOTE Only the measurement uncertainty of the measured values is shown in Example A.3.3. The calculation method for the uncertainty of the daily vibration exposure is shown in Example A.3.4.5 for comparable workplaces.

— The measurement results are used for the evaluation of other workplaces with the same work task (same type of working device, but other serial number, other user).

A.3.4.2 Uncertainty of the measurement results for the measured workplace

Besides the scattering of the repeated measurements, the uncertainties of the measuring instrument, the coupling and the transducer position shall also be considered for the evaluation of the workplace at which the measurement was performed.

The following example refers to test subject 2 and, to illustrate the components of the uncertainties of the measuring body, i.e. $u(x_1)$ to $u(x_3)$, to the data for rotary hammers (relative uncertainty):

$u_{\text{measuring instrument}} = u(x_1) = 0{,}152$ Field application (from Table A.1)

$u_{\text{coupling}} = u(x_2) = 0{,}029$ Transducer coupling (from Table A.1)

$u_{\text{measurement point}} = u(x_3) = 0{,}173$ Transducer position (from Table A.1)

$u_{\text{repeatability}} = u(x_4)_{a\ \text{corr}}$ Dependent on the measurement series (from Table A.5).

This can be used to determine the combined relative uncertainty u_c for each activity m as follows:

$$u_c = \sqrt{\sum_i u^2(x_i)}$$

$$= \sqrt{u^2_{\text{measuring instrument}} + u^2_{\text{coupling}} + u^2_{\text{measurement point}} + u^2_{\text{repeatability}}}$$

$$u_{c,\text{impact drill (wall)}} = \sqrt{0{,}152^2 + 0{,}029^2 + 0{,}173^2 + 0{,}076^2} = 0{,}244$$

$$u_{c,\text{impact drill (metal)}} = \sqrt{0{,}152^2 + 0{,}029^2 + 0{,}173^2 + 0{,}231^2} = 0{,}328$$

$$u_{c,\text{milling machine}} = \sqrt{0{,}152^2 + 0{,}029^2 + 0{,}173^2 + 0{,}187^2} = 0{,}298$$

A.3.4.3 Transferring the results to comparable workplaces

When transferring the results to comparable workplaces, the scatterings due to the test subjects (operators) and the production of the machines used (product scattering, see Note 2 to 3.25) shall be added to the uncertainties considered under A.3.4.2 for one workplace.

If the test subject scattering cannot be determined by measurements with several test subjects or there are no values available for the product scattering, the values from Table A.1 can be used as approximations. It is recommended that the highest workplace value from the individual test subjects is used when transferring results to comparable workplaces; in this example, the values of test subject 2 from A.3.4.2 are used:

$u_{\text{workplace}}$	Result from A.3.4.2 (uncertainty of one test subject at one workplace)
$u_{\text{test subject}} = 0{,}087$	Test subject standard deviation (from Table A.1)
$u_{\text{product}} = 0{,}046$	Production standard deviation (from Table A.1)

This can be used to determine the combined relative uncertainty u_c for each activity m at comparable workplaces as follows:

$$u_c = \sqrt{\sum_i u^2(x_i)}$$

$$= \sqrt{u_{\text{workplace}}^2 + u_{\text{test subject}}^2 + u_{\text{product}}^2}$$

$$u_{c,\text{impact drill (wall)}} = \sqrt{0{,}244^2 + 0{,}087^2 + 0{,}046^2}$$

$$= 0{,}263 \mathrel{\hat{=}} \text{a combined (absolute) uncertainty of } 3{,}42\ \text{m/s}^2$$

$$u_{c,\text{impact drill (metal)}} = \sqrt{0{,}328^2 + 0{,}087^2 + 0{,}046^2}$$

$$= 0{,}342 \mathrel{\hat{=}} \text{a combined (absolute) uncertainty of } 1{,}88\ \text{m/s}^2$$

$$u_{c,\text{milling machine}} = \sqrt{0{,}298^2 + 0{,}087^2 + 0{,}046^2}$$

$$= 0{,}314 \mathrel{\hat{=}} \text{a combined (absolute) uncertainty of } 0{,}94\ \text{m/s}^2$$

A.3.4.4 Expanded uncertainty and indication of the measurement result

For the one-sided coverage interval (one-sided test), an expanded uncertainty U with an assumed coverage probability of 95 % according to Table 2 produces the following result:

Impact drill (wall):	$U = k \cdot u_c = 1{,}6 \times 3{,}42\ \text{m/s}^2 = 5{,}5\ \text{m/s}^2$
Impact drill (metal):	$U = k \cdot u_c = 1{,}6 \times 1{,}88\ \text{m/s}^2 = 3{,}0\ \text{m/s}^2$
Milling machine:	$U = k \cdot u_c = 1{,}6 \times 0{,}94\ \text{m/s}^2 = 1{,}5\ \text{m/s}^2$

The vibration total value a_{hv} of the individual activities at comparable workplaces shall be indicated as follows (see Table A.5):

Impact drill (wall): $a_{\text{hv}} = (13,0 + 5,5)\ \text{m/s}^2$

Impact drill (metal): $a_{\text{hv}} = (5,5 + 3,0)\ \text{m/s}^2$

Milling machine: $a_{\text{hv}} = (3,0 + 1,5)\ \text{m/s}^2$

A.3.4.5 Calculation of the daily vibration exposure value $A(8)$ and of the uncertainty of the exposure duration

Besides the evaluated accelerations, the exposure durations shall be considered for determination of the daily vibration exposure value.

The estimation of the uncertainty is carried out for the exposure duration according to Formula (14) and is indicated in Table A.6.

Table A.6 — Exposure duration and its uncertainty

Time in min

i	**Machine** (activity)	**Exposure duration** $t_{e,i}$	**Mean value** $\overline{t_{e,i}}$	**Half period** Δt	**Uncertainty** $u(x_i)_t$
1	Impact drill (wall)	10 to 15	12,5	2,5	1,44 (0,115 2)[a]
2	Impact drill (metal)	10 to 15	12,5	2,5	1,44 (0,115 2)[a]
3	Milling machine	40 to 60	50	10	5,77 (0,115 4)[a]

[a] The values in brackets are relative values without unit.

According to Formula (14), this yields the following uncertainty for the exposure duration for the impact drill:

$$u(x_i)_t = \frac{\Delta t}{\sqrt{3}} = \frac{2,5\ \text{min}}{\sqrt{3}} = 1,44\ \text{min} \tag{A.7}$$

The daily vibration exposure value $A(8)$ of all three activities is calculated from the mean values according to Table A.4 and Table A.6 for test subject 2 as follows:

$$A(8) = \sqrt{\frac{1}{8\,\text{h}} \sum_{i=1}^{3} \overline{a_{\text{hv}i}}^2\, \overline{t_{e,i}}} = \sqrt{\frac{1}{480\,\text{min}}\left[\left(13,0\,\text{m/s}^2\right)^2 \times 12,5\,\text{min} + \left(5,5\,\text{m/s}^2\right)^2 \times 12,5\,\text{min} + \left(3,0\,\text{m/s}^2\right)^2 \times 50\,\text{min}\right]} = 2,48\,\text{m/s}^2 \tag{A.8}$$

A.3.4.6 Calculation of the uncertainty of the daily vibration exposure value $A(8)$

The general definition of the daily vibration exposure value $A(8)$ over i = 1 to m exposure time sections T_i with the applicable vibration total value a_{vi}

$$A(8)=\sqrt{\frac{1}{8\ \text{h}}\sum_{i=1}^{m} a_{vi}^2 T_i} \tag{A.9}$$

gives the sensitivity coefficients for the uncertainty components of the acceleration according to Formula (8) as

$$c_{a,i}=\frac{\partial A(8)}{\partial a_{vi}}=\frac{1}{8\ \text{h}}\frac{a_{vi}T_i}{A(8)} \tag{A.10}$$

and those for the uncertainty components of the time therefore as

$$c_{T,i}=\frac{\partial A(8)}{\partial T_i}=\frac{1}{2\times 8\ \text{h}}\frac{a_{vi}^2}{A(8)} \tag{A.11}$$

The combined standard uncertainty for the daily vibration exposure value $A(8)$ according to Formula (9) is therefore

$$u_c\left(A(8)\right)=\sqrt{\sum_i\left(c_{a,i}^2 u^2(a_{vi})+c_{T,i}^2 u^2(T_i)\right)} \tag{A.12}$$

A.3.4.7 Calculation example

NOTE 1 The following calculation example is shown without units for reasons of clarity. The acceleration values have the unit m/s^2 and time has the unit min.

The example refers to test subject 2.

According to Formula (A.10), the sensitivity coefficients for the uncertainty components of acceleration are

$$c_{a,\text{impact drill (wall)}}=\frac{1}{8\times 60}\frac{13{,}0\times 12{,}5}{2{,}48}=0{,}1357$$

$$c_{a,\text{impact drill (metal)}}=\frac{1}{8\times 60}\frac{5{,}5\times 12{,}5}{2{,}48}=0{,}0578$$

$$c_{a,\text{milling machine}}=\frac{1}{8\times 60}\frac{3{,}0\times 50}{2{,}48}=0{,}1260$$

According to Formula (A.11), the sensitivity coefficients for the uncertainty components of time are

$$c_{T,\text{impact drill (wall)}}=\frac{1}{2\times 8\times 60}\frac{13{,}0^2}{2{,}48}=0{,}0710$$

$$c_{T,\text{impact drill (metal)}}=\frac{1}{2\times 8\times 60}\frac{5{,}5^2}{2{,}48}=0{,}0127$$

$$c_{T,\text{milling machine}} = \frac{1}{2\times 8\times 60}\frac{3{,}0^2}{2{,}48} = 0{,}0038$$

The combined standard uncertainties of the individual activities are (see terms in Formula (A.12))

$$u_{\text{c,impact drill (wall)}} = \sqrt{0{,}1357^2\times 3{,}42^2 + 0{,}0710^2\times 1{,}44^2} = 0{,}4752$$

$$u_{\text{c,impact drill (metal)}} = \sqrt{0{,}0578^2\times 1{,}88^2 + 0{,}0127^2\times 1{,}44^2} = 0{,}1100$$

$$u_{\text{c,milling machine}} = \sqrt{0{,}1260^2\times 0{,}94^2 + 0{,}0038^2\times 5{,}77^2} = 0{,}1204$$

According to Formula (A.12), the combined standard uncertainty of the daily vibration exposure value is

$$u_\text{c} = A(8) = \sqrt{0{,}2524} = 0{,}502\ \text{m/s}^2$$

NOTE 2 Rounding in the calculation process results in deviations from the third decimal place on.

This results in an expanded uncertainty for the assumed coverage probability of 95 % according to Table 2 and Formula (10):

— in a one-sided test: $U = k\cdot u_\text{c} = 1{,}6\times 0{,}5\ \text{m/s}^2 = 0{,}8\ \text{m/s}^2$

— in a two-sided test: $U = k\cdot u_\text{c} = 2\times 0{,}5\ \text{m/s}^2 = 1{,}0\ \text{m/s}^2$

As a comparison of limit value is undertaken when determining the workplace exposure in this example, the one-sided test applies. As a result, the daily vibration exposure value $A(8)$ according to Formula (17) is as follows:

$$A(8) = (2{,}48 \pm 0{,}80)\ \text{m/s}^2$$

NOTE 3 In the above calculation three digits are given, but for measured values a declaration of two digits would be rational.

A.3.4.8 Interpretation of results

The vibration exposure of the window fitter is $A(8) = 2{,}48\ \text{m/s}^2 \pm 0{,}80\ \text{m/s}^2$ (see A.3.4.5). For comparison with a limit value, the one-sided test is utilized (see A.3.4.7) and, taking the uncertainty of $A(8)$ into account, the daily vibration exposure value is maximum 3,28 m/s^2 with a coverage probability of 95 %.

NOTE With a coverage probability of 95 %, this daily vibration exposure value is maximum 3,28 m/s^2 and therefore is still below the exposure limit value of 5 m/s^2, but above the action value of 2,5 m/s^2, both values being commonly used in national or regional legislative specifications.

Annex B
(informative)

Example for determination of the measurement uncertainty of emission measurements on hand-held and hand-guided machines

Considering measurement uncertainty in emission measurements on hand-held and hand-guided machines, i.e. for determining vibration emission values, is a provision of the Machinery Directive which requires that uncertainty is also to be indicated with the measured vibration emission values. Furthermore, the measurement uncertainty is a quantitative indicator of the quality of the results, which can be used to evaluate the reliability of a result.

In general, the measurement uncertainty of hand-held and hand-guided machines – for example as in the standards series IEC 60335, IEC 60745, IEC 61029 and ISO 28927 – is determined according to or along the lines of EN 12096. The method is described in sufficient detail in the above- mentioned standards.

Determination of the uncertainty of an emission measurement on a machine according to one of the above standards on the basis of ISO/IEC Guide 98-3 is described below. This uncertainty can be used to estimate the true vibration total value. The determination is based on the five measured values determined by each of the three operators (test subjects) on one machine.

Table B.1 — Example values for determination of the measurement uncertainty

Acceleration in m/s^2

Test subject	Vibration total value a_{hv} of the individual measurements					Mean value
	Measurement					
	1	2	3	4	5	
1	4,0	4,2	4,1	4,3	4,0	4,1
2	4,2	4,2	4,3	4,0	4,2	4,2
3	4,2	4,0	4,1	4,1	4,0	4,1
Averaged vibration value a_h = 4,1						

When determining the measurement uncertainty of hand-held and hand-guided machines, it is recommended that the total measurement uncertainty according to ISO/IEC Guide 98-3 is divided into two different groups of uncertainty components.

a) Type A evaluation,

b) Type B evaluation.

Type A evaluation in this case is a method of calculating the uncertainty components via statistical analysis of series of observations, whereby the uncertainty can be determined from the directly read measured values. All other components (uncertainty of the measurement technology, uncertainty of the transducer coupling, etc.) cannot be determined from the current measured values and shall therefore be determined according to Type B evaluation. Such components may include data from previous measurements, information from the manufacturer, empirical values, data from calibration certificates and manuals, etc.

This gives the standard uncertainty components according to Type A evaluation from the standard deviation of the mean value. The consequence is that the standard uncertainty for the determined values can be reduced, the more measurements are performed. If the number of measurement readings increases towards infinity, the standard uncertainty converges towards zero for the measured value. However, for practical reasons, the measurement standards define determination of five measured values in each case by three operators. As the number of repeated measurements is therefore specified as n = 5, the individual standard uncertainties are still corrected with the Bayes term according to Formula (13), which has the value 1,41 when n = 5. This gives the values in Table B.2.

Table B.2 — Summary of the individual components of the standard uncertainty according to Type A evaluation

Variable	Standard uncertainty u_i m/s^2	Sensitivity coefficient c_i	$c_i\, u_{i\ corr}$ m/s^2
$\delta_{operator1}$	0,06	1	0,08
$\delta_{operator2}$	0,05	1	0,07
$\delta_{operator3}$	0,04	1	0,05

The maximum standard uncertainty of the individual test subjects should be used to calculate the measurement uncertainty. In the case under consideration, the maximum corrected standard uncertainty according to Table B.2 is 0,08 m/s^2 by test subject 1. This consideration of the least favourable case should be chosen for the best possible estimation of all occurring scatterings of results for the measurements. It shall also be noted that according to the underlying standard the repeatability standard deviation does not exceed σ = 0,3 m/s^2 and the coefficient of variation does not exceed C_v = 0,15.

All other uncertainty components, such as the uncertainty from the applied measurement technology, however, remain dependent on the number of individual measurements. These standard uncertainty components according to Type B evaluation are obtained from the stated standard deviations or by dividing the stated value by the coverage factor, if the expanded measurement uncertainty is given (see Table B.3).

Table B.3 — Summary of the individual components of the standard uncertainty for rotary hammers according to Type B evaluation

	Empirical value for expected uncertainties according to Table A.1 %	Standard uncertainty u_i at a vibration total value of 4,1 m/s^2 according to Table B.1 m/s^2
Position of the transducer	30	1,23
Transducer coupling	5	0,21
Uncertainty of the measurement system (for laboratory application)	10	0,41
Uncertainty of the operators (test subject scattering)	15	0,62
Further uncertainty components[a] (e.g. scattering from test benches, tools and materials)	—	—

[a] If further uncertainty components are known, they should be added.

On the assumption that the specified single components are independent of each other and have normal distribution, and that the output quantity has a linear relation to the input quantity, the sensitivity coefficient for all uncertainty components is c_i = 1.