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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
$\overline{x}$
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:

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

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

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

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:

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

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