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Methods for the calibration of vibration and shock transducers —

Part 21:
Vibration calibration by comparison to a reference transducer

Méthodes pour l'étalonnage des transducteurs de vibrations et de chocs —

Partie 21: Étalonnage de vibrations par comparaison à un transducteur de référence

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16063-21 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 3, *Use and calibration of vibration and shock measuring instruments*.

This first edition of ISO 16063-21 cancels and replaces ISO 5347-3:1993, which has been technically revised.

ISO 16063 consists of the following parts, under the general title *Methods for the calibration of vibration and shock transducers*:

— *Part 1: Basic concepts*

— *Part 11: Primary vibration calibration by laser interferometry*

— *Part 12: Primary vibration calibration by the reciprocity method*

— *Part 13: Primary shock calibration using laser interferometry*

— *Part 21: Vibration calibration by comparison to a reference transducer*

— *Part 22: Shock calibration by comparison to an accelerometer, velocity or force transducer*

Introduction

The ISO 16063 series of standards is concerned with methods for the calibration of vibration and shock transducers under both standard laboratory conditions and in the field.

As such, the intended user group of this part of ISO 16063 is wide, ranging from metrologists in mechanical vibration to technicians evaluating the vibration characteristics of a machine or structure, or human exposure to vibration. The key to the application of this part of ISO 16063 is in the careful detailed specification and evaluation of measurement uncertainty, i.e. the error budget and computation of expanded uncertainty associated with the measurement of vibration.

This part of ISO 16063 is particularly intended for those engaged in vibration measurements requiring traceability to primary national or international standards through a secondary, reference, working or check standard (portable calibrator intended for field use) as defined in the *International vocabulary of basic and general terms in metrology* (VIM). The specifications for the instrumentation and the procedures given are intended to be used for calibration of rectilinear vibration transducers (with or without signal conditioning) to obtain the magnitude and (optionally) phase shift of the complex sensitivity at frequencies in the range of 0,4 Hz to 10 kHz.

Methods for the calibration of vibration and shock transducers —

Part 21: Vibration calibration by comparison to a reference transducer

1 Scope

This part of ISO 16063 describes the calibration of rectilinear vibration transducers by comparison. Although it mainly describes calibration using direct comparison to a standard calibrated by primary methods, the methods described can be applied between other levels in the calibration hierarchy.

This part of ISO 16063 specifies procedures for performing calibrations of rectilinear vibration transducers by comparison in the frequency range from 0,4 Hz to 10 kHz. It is primarily intended for those who are required to meet ISO standardized methods for the measurement of vibration under laboratory conditions, where the uncertainty of measurement is relatively small. It can also be used under field conditions, where the uncertainty of measurement may be relatively large.

From knowledge of all significant sources of uncertainty affecting the calibration, the expanded uncertainty can be evaluated using the methods given in this part of ISO 16063. It also covers the assessment of uncertainties for calibrations performed using a check standard.

Comparison calibrations made in accordance with this part of ISO 16063 need to allow for the environmental conditions of the reference transducer calibration.

NOTE Transducer calibrations made under extreme environmental conditions are covered by other International Standards.

2 Normative references

The following referenced documents are indispensable for the application 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 266, *Acoustics — Preferred frequencies*

ISO 2041:1990, *Vibration and shock — Vocabulary*

ISO 16063-1:1998, *Methods for the calibration of vibration and shock transducers — Part 1: Basic concepts*

ISO 16063-11:1999, *Methods for the calibration of vibration and shock transducers — Part 11: Primary vibration calibration by laser interferometry*

Guide to the expression of uncertainty in measurement (GUM). BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1993[1)]

1) Corrected and reprinted in 1995.

3 Uncertainty of measurement

3.1 All users of this part of ISO 16063 are expected to make uncertainty budgets according to Annex A to document their level of uncertainty (see example in Annex D).

To help set up systems fulfilling different requirements two examples are given. System requirements for each are set up and the attainable uncertainty is given. Example 1 is typical for calibrations under well-controlled laboratory conditions with the requirement to obtain a high accuracy. Example 2 is typical for calibrations where less than the highest accuracy can be accepted or where calibration conditions are such that only less narrow tolerances can be maintained. These two examples will be used throughout this part of ISO 16063.

a) **Example 1**

The reference transducer is calibrated by primary means and documented uncertainty. The calibration may be transferred to a working standard for practical reasons. The temperature and other conditions are kept within narrow limits during the comparison calibration as indicated in the appropriate clauses.

b) **Example 2**

The reference transducer is not calibrated by primary means, but has a traceable calibration, as defined in VIM (see [2]), with the corresponding uncertainty documented. The calibration may be transferred to a working standard for practical reasons. The requirements on other parameters and instruments are indicated in the appropriate clauses.

3.2 For both examples, the minimum calibration requirement for the reference transducer is calibration under suitable reference conditions (i.e. frequency, amplitude and temperature). Normally the conditions will be chosen as indicated in ISO 16063-11.

It is applicable for the following parameters:

Frequency range: 20 Hz to 5 000 Hz, optionally 0,4 Hz to 10 000 Hz (see Note 1)

Dynamic range: 10 m/s^2 to 1 000 m/s^2 r.m.s., optionally 0,1 m/s^2 to 1 000 m/s^2 (frequency dependent)

NOTE The indicated frequency ranges are not mandatory and single-point calibrations are also acceptable.

At any given frequency and amplitude of acceleration, velocity or displacement, the dynamic range will be limited by the noise floor and the amount of distortion produced by the excitation apparatus (if no filtering is used) or its maximum power. (Techniques are also used to counteract the inherent distortion at large displacements for spring-controlled exciters by changing the waveform of the input voltage.) Typical maximum values for electrodynamic vibration exciters designed for the frequency range from 10 Hz to 10 kHz are 200 m/s^2 to 1000 m/s^2 r.m.s. acceleration, 0,5 m/s to 1 m/s r.m.s. velocity and 5 mm peak displacement. The lower limits will be set by the noise in the two measurement channels, and by the bandwidth used. Typical values used for measurement are 50 m/s^2 to 100 m/s^2 r.m.s. acceleration or 0,1 m/s r.m.s. velocity. For calibrators, values between 1 m/s^2 and 10 m/s^2 r.m.s. are normally used. A graph similar to the one shown in Annex C is useful when considering the ranges covered.

When measurements are performed at the lowest frequencies, the limiting factor is normally displacement. At 1 Hz, typical values for long-stroke vibrators are 1 m/s^2 to 2 m/s^2 r.m.s. acceleration or 0,1 m/s to 0,3 m/s r.m.s. velocity.

3.3 The attainable uncertainties (expanded uncertainties calculated using a coverage factor of 2 in accordance with ISO 16063-1) for the two examples are given in Table 1. In practice, these limits may be exceeded depending on the uncertainty with which the reference transducer has been calibrated, the response characteristics of the reference transducer and the transducer to be calibrated, the vibratory characteristics of the exciter and the instrumentation used in the measurement apparatus. It is the responsibility of the laboratory or end user to make sure that the reported values of expanded uncertainty are credible.

Table 1 — Attainable uncertainties of magnitude and phase shift of the complex sensitivity

Parameter	Example 1	Example 2
Magnitude		
For accelerometers (0,4 Hz to 1 000 Hz)	1 %	3 %
For accelerometers (1 000 Hz to 2 000 Hz)	2 %	5 %
For accelerometers (2 kHz to 10 kHz)	3 %	10 %
For displacement and velocity transducers (20 Hz to 1 000 Hz)	4 %	6 %
Phase shift [a]		
At reference conditions [b] (i.e. the level and frequency at which the reference transducer was calibrated)	1°	3°
Outside reference conditions	2,5°	5°

[a] Phase shift measurement is not mandatory.

[b] Recommended reference conditions are as follows (from ISO 16063-11:1999, Clause 2):

— frequency in hertz: 160, 80, 40, 16 or 8 (or angular frequency ω in radians per second: 1000, 500, 250, 100 or 50),

— acceleration in metres per second squared (acceleration amplitude or r.m.s. value): 100, 50, 20, 10, 5, 2 or 1.

NOTE The expanded uncertainties given as examples (e.g. 1 %) are based on concrete uncertainty budgets such as given in Annex D as an example (resulting expanded uncertainty 0,84 %).

4 Requirements for apparatus and environmental conditions

4.1 General

The examples referred to in this clause are those described in Clause 3.

If the recommended specifications listed below are met for each item, the uncertainties given in Clause 3 should be obtainable over the applicable frequency range depending on the uncertainty with which the reference transducer has been calibrated, and the response characteristics of the reference transducer and transducer to be calibrated. Other combinations of requirements can, however, lead to the same uncertainty. Special instrumentation may be required in order to meet the expanded uncertainties given in Clause 3 at frequencies less than 1 Hz. It is mandatory to document the expanded uncertainty using the methods of Annex A.

4.2 Environmental conditions

These shall be the following.

	Example 1	Example 2
Room temperature	(23 ± 5) °C	(23 ± 10) °C
Relative humidity	75 % max.	90 % max.

4.3 Reference transducer

This should preferably be calibrated together with the amplifier.

a) **Example 1**

The transducer shall be calibrated in accordance with suitable primary methods or by comparison against a transducer calibrated in accordance with suitable primary methods (see ISO 16063-11 or other parts) with an expanded uncertainty of 0,5 % (magnitude) and 0,5° (phase shift) at selected reference frequency and acceleration (the uncertainties are those obtained when calculating expanded uncertainties using a coverage factor of 2). Higher uncertainty values are accepted at high and low frequencies.

b) **Example 2**

The transducer shall be calibrated by suitable and known methods with traceability to a primary reference transducer and an uncertainty of less than 2 % (magnitude) and 2° (phase shift) at selected reference frequency and acceleration (the uncertainties are those obtained when calculating expanded uncertainties using a coverage factor of 2). Higher uncertainty values are accepted at high and low frequencies.

The reference transducer may be of the so-called back-to-back type meant for direct mounting of the transducer to be calibrated on top of it in a so-called back-to-back configuration (see Figure 1). It may also be a transducer with normal mounting provisions used underneath a fixture in line with the transducer to be calibrated. It is not recommended to mount the two transducers side by side as rocking motions will often be present, causing large errors in many circumstances. For calibrators, the reference transducer may be an integral part of a moving element.

Subclauses 4.4 to 4.8 specify characteristics of apparatus that contribute to the uncertainty of measurement.

4.4 Vibration generation equipment

This shall fulfil the requirements given in Table 2.

Table 2 — Vibration generation equipment

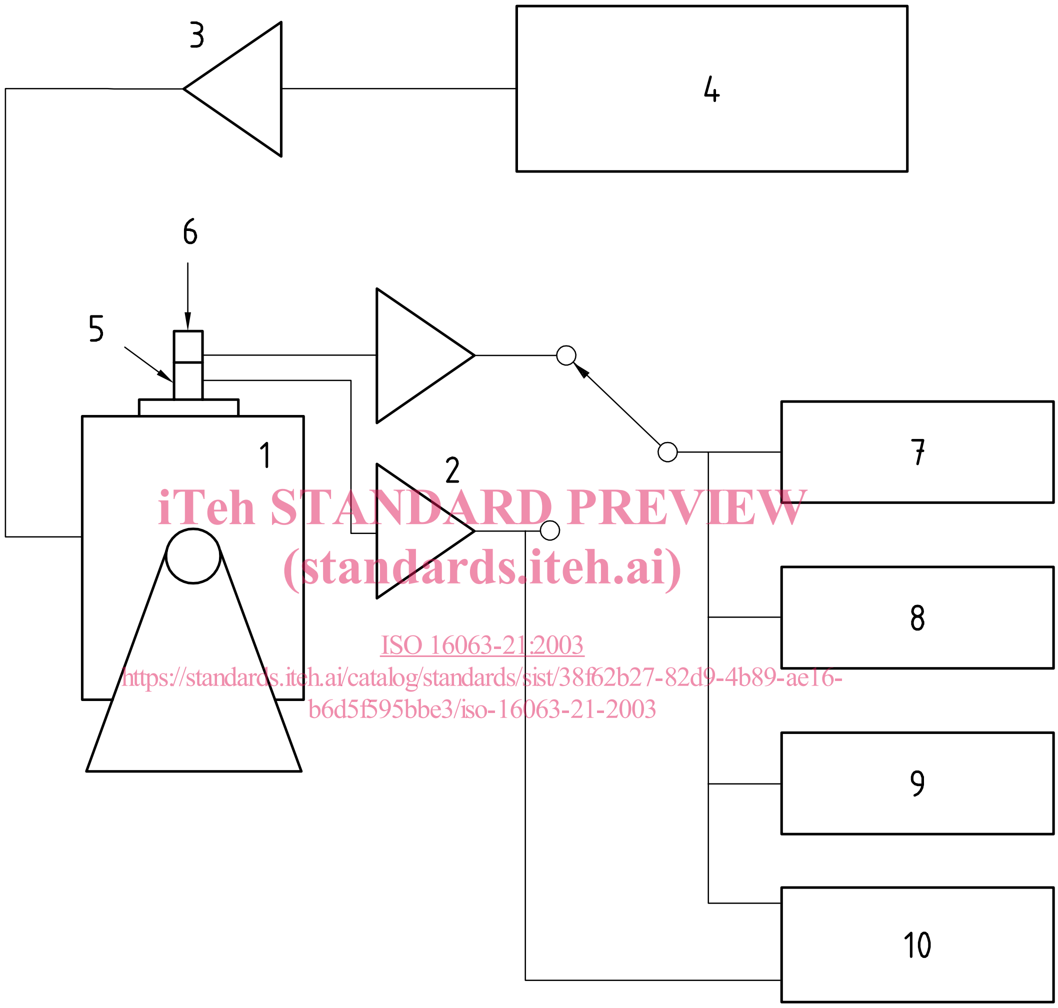
Parameter	Unit	Example 1	Example 2
Frequency uncertainty	%	⩽ 0,1	⩽ 0,2
Frequency stability	% of reading over the measurement period	0,1	0,2
Acceleration amplitude stability	% of reading over the measurement period	0,1	0,3
Total harmonic distortion at frequencies > 20 Hz	%	⩽ 5	⩽ 10
Total harmonic distortion over the whole frequency range	%	⩽ 10	⩽ 20
Transverse, bending and rocking acceleration	%	⩽ 10 at f ⩽ 1 kHz ⩽ 30 at f > 1 kHz	
Hum and noise (f ⩾ 10 Hz)	dB below full output	⩾ 50	⩾ 40
Hum and noise (f < 10 Hz)	dB below full output	⩾ 20	⩾ 10

The hum and noise will only be important when inside the measurement bandwidth used. For every combination of frequency, acceleration and load that is used during calibration, the magnitude of the transverse, bending and rocking accelerations, hum and noise shall be consistent with the uncertainties given in Clause 3.

Static or dynamic base strain introduced to the transducer from the attachment surfaces shall not unduly influence the calibration result.

All mounting surfaces between any two transducers compared shall have flatness and roughness specifications suitable for the purpose. If the highest frequency range is used, strict tolerances are necessary. The surface on which the transducer is to be mounted shall have a roughness value, expressed as the arithmetical mean deviation Ra of < 1 µm. The flatness shall be such that the surface is contained between two parallel planes 5 µm apart, over the area corresponding to the maximum mounting surface of any transducer to be calibrated. The drilled and tapped hole for connecting the transducer shall have a perpendicularly tolerance to the surface of < 10 µm, i.e. the centreline of the hole shall be contained in a cylindrical zone with 10 µm diameter and a height equal to the hole depth.

The mounting surface of the vibration exciter should be perpendicular to the direction of motion. Any deviation from perpendicularity should be taken into account in the uncertainty budget, see Annex A.



Key

1 exciter
2 amplifiers
3 power amplifier
4 frequency generator and indicator
5 reference transducer
6 transducer to be calibrated
7 voltmeter
8 distortion meter for occasional checks
9 oscilloscope for visual inspection (optional)
10 phase meter (optional)

Figure 1 — Example of a measuring system for vibration calibration by comparison to a reference transducer

NOTE 1 Multisine, sine or random generators can be used in conjunction with frequency analysers. Typically Fast Fourier Transform (FFT) analysers are used for random and multisine signals and Single-Sine Correlation or Frequency Response Analysers (FRA) are used for single-sine signals. The distortion is then normally of no importance. Therefore analysers are normally preferred instead of broadband r.m.s. voltmeters which, although fundamentally more accurate, are sensitive to distortion and other signals at frequencies differing from the measurement frequency. Measurement of coherence can be used to estimate whether or not the signal-to-noise ratio and the linearity of the transducers are within well-defined limits when spectral averaging is used. With random excitation and 64 averages a minimum coherence limit of 0,98 will ensure that the errors due to signal-to-noise ratio and linearity are less than 0,9 % for a dual channel measurement. In rare cases, broadband excitation can, however, create unwanted (transverse) vibration or output signals at a measuring frequency due to non-linear behaviour of shaker or transducer at other frequencies.

NOTE 2 The items in 4.3 and 4.4 may be integrated into a calibrator.

4.5 Voltage measuring instrumentation

Two alternative set-ups are considered.

a) A single voltmeter measuring true r.m.s. at transducer amplifier output is used. The outputs from the reference transducer and the transducer to be calibrated are measured consecutively and the reference transducer output at least twice. This equipment shall fulfil the requirements given in Table 3.

Table 3 — Voltage measuring instrumentation — Single voltmeter

Parameter	Unit	Example 1	Example 2
Frequency range	Hz	1 to 10 000	1 to 10 000
Maximum deviation from linearity	% of reading for max. difference in signal levels	0,1	0,3
Maximum deviation between two consecutive reference transducer measurements	%	0,1	0,3

NOTE The last row describes the repeatability of the measurement. This includes more than the voltmeter repeatability but is treated here as a general requirement.

b) An instrument measuring voltage ratio between transducer amplifier outputs is used. This equipment shall have the characteristics specified in Table 4.

Table 4 — Voltage measuring instrumentations

Parameter	Unit	Example 1	Example 2
Frequency range	Hz	1 to 10 000	1 to 10 000
Maximum uncertainty	%	0,2	0,5

4.6 Distortion measuring instrumentation

Distortion measuring instrumentation (limited use, see Note) capable of measuring total harmonic distortion of 1 % to 10 % shall have the characteristics specified in Table 5.

Table 5 — Distortion measuring instrumentation

Parameter	Unit	Example 1	Example 2
Frequency range	Hz	1 to 50 000	1 to 50 000
Maximum uncertainty	% of reading	10	10

NOTE Distortion measurement is only needed for sine calibration and is not included in the standard procedure. It is used to check the performance of the vibration generating equipment initially and then only with suitable intervals or in case of doubt.