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Methods for the calibration of vibration and shock transducers —

Part 43: Calibration of accelerometers by model-based parameter identification

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

Partie 43: Étalonnage des accéléromètres par identification des paramètres à base de modèle

Reference number
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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.

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 3, *Use and calibration of vibration and shock measuring instruments*.

This corrected version of ISO 16063-43:2015 incorporates the following corrections:

— Formulae (26) and (32) corrected;

— symbol i used for the imaginary unit; symbol χ used where necessary; symbols *R* and *J* used to indicate real and imaginary parts;

— Figures 3 and 4 brought in line with the formulae in the text;

— editorial improvements, including "transducer" used instead of "sensor" or "pick-up";

— Reference [6] corrected.

— application of the ISO/IEC Directives, Part 2, 2016.

A list of all the parts in the ISO 16063 series can be found on the ISO website.

Introduction

The ISO 16063 series describes in several of its parts (ISO 16063-1, ISO 16063-11, ISO 16063-13, ISO 16063-21 and ISO 16063-22) the devices and procedures to be used for calibration of vibration transducers. The approaches taken can be divided in two classes: one for the use of stationary signals, namely sinusoidal or multi-sinus excitation; and the other for transient signals, namely shock excitation. While the first provides the lowest uncertainties due to intrinsic and periodic repeatability, the second aims at the high intensity range where periodic excitation is usually not feasible due to power constraints of the calibration systems.

The results of the first class are given in terms of a complex transfer sensitivity in the frequency domain and are, therefore, not directly applicable to transient time domain application.

The results of the second class are given as a single value, the peak ratio, in the time domain that neglects (knowingly) the frequency-dependent dynamic response of the transducer to transient input signals with spectral components in the resonance area of the transducer's response. As a consequence of this "peak ratio characterization", the calibration result might exhibit a strong dependence on the shape of the transient input signal applied for the calibration and, therefore, from the calibration device.

This has two serious consequences:

a) The calibration with shock excitation in accordance with ISO 16063-13 or ISO 16063-22 is of limited use as far as the dissemination of units is concerned. That is, the shock sensitivities S_{sh} determined by calibrations on a device in a primary laboratory might not be applicable to the customer's device in the secondary calibration lab, simply due to a different signal shape and thus spectral constitution of the secondary device's shock excitation signal.

b) A comparison of calibration results from different calibration facilities with respect to consistency of the estimated measurement uncertainties, e.g. for validation purposes in an accreditation process, is not feasible if the facilities apply input signals of differing spectral composition.

The approach taken in this document is a mathematical model description of the accelerometer as a dynamic system with mechanical input and electrical output, where the latter is assumed to be proportional to an intrinsic mechanical quantity (e.g. deformation). The estimates of the parameters of that model and the associated uncertainties are then determined on the basis of calibration data achieved with established methods (ISO 16063-11, ISO 16063-13, ISO 16063-21 and ISO 16063-22). The complete model with quantified parameters and their respective uncertainties can subsequently be used to either calculate the time domain response of the transducer to arbitrary transient signals (including time-dependent uncertainties) or as a starting point for a process to estimate the unknown transient input of the transducer from its measured time-dependent output signal (ISO 16063-11 or ISO 16063-13).

As a side effect, the method also usually provides an estimate of a continued frequency domain transfer sensitivity of the model.

In short, this document prescribes methods and procedures that enable the user to

— calibrate vibration transducers for precise measurements of transient input,

— perform comparison measurements for validation using transient excitation,

— predict transient input signals and the time-dependent measurement uncertainty, and

— compensate the effects of the frequency-dependent response of vibration transducers (in real time) and thus expand the applicable bandwidth of the transducer.

Methods for the calibration of vibration and shock transducers —

Part 43: Calibration of accelerometers by model-based parameter identification

1 Scope

This document prescribes terms and methods on the estimation of parameters used in mathematical models describing the input/output characteristics of vibration transducers, together with the respective parameter uncertainties. The described methods estimate the parameters on the basis of calibration data collected with standard calibration procedures in accordance with ISO 16063-11, ISO 16063-13, ISO 16063-21 and ISO 16063-22. The specification is provided as an extension of the existing procedures and definitions in those International Standards. The uncertainty estimation described conforms to the methods established by ISO/IEC Guide 98-3 and ISO/IEC Guide 98-3/Supplement 1.

The new characterization described in this document is intended to improve the quality of calibrations and measurement applications with broadband/transient input, like shock. It provides the means of a characterization of the vibration transducer’s response to a transient input and, therefore, provides a basis for the accurate measurement of transient vibrational signals with the prediction of an input from an acquired output signal. The calibration data for accelerometers used in the aforementioned field of applications should additionally be evaluated and documented in accordance with the methods described below, in order to provide measurement capabilities and uncertainties beyond the limits drawn by the single value characterization given by ISO 16063-13 and ISO 16063-22.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their 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 16063-11, *Methods for the calibration of vibration and shock transducers — Part 11: Primary vibration calibration by laser interferometry*

ISO 16063-13, *Methods for the calibration of vibration and shock transducers — Part 13: Primary shock calibration using laser interferometry*

ISO 16063-21, *Methods for the calibration of vibration and shock transducers — Part 21: Vibration calibration by comparison to a reference transducer*

ISO 16063-22, *Methods for the calibration of vibration and shock transducers — Part 22: Shock calibration by comparison to a reference transducer*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 98-3/Supplement 1, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995) — Supplement 1: Propagation of distributions using a Monte Carlo method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041 apply.

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

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

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

4 List of symbols

The symbols used in the formulae are listed in order of occurrence in the text.

$x, \dot{x}, \ddot{x}$	Output quantity of the respective transducer and its single and double derivative over time
δ	Damping coefficient of the model equation in the time domain
ω_0	Circular resonance frequency of the model
ρ	Electromechanical conversion factor
i	Imaginary unit, $\mathrm{i} = \sqrt{-1}$
H	Complex valued transfer function
S	Magnitude of the transfer function
ϕ	Phase of the transfer function
G	Reciprocal of the complex valued transfer function
μ	Parameter vector
S_m	Magnitude of the transfer function for a circular frequency, ω_m
ϕ_m	Phase of the transfer function for a circular frequency, ω_m
R	Real part of the complex valued transfer function
J	Imaginary part of the complex valued transfer function
y	Vector of real and imaginary parts of the measured transfer function
V_y	Covariance matrix of y
D	Coefficients matrix
$\hat{\mu}$	Vector of parameter estimates
$V_{\hat{\mu}}$	Covariance matrix of $\hat{\mu}$
S_0	Magnitude of the transfer function at low frequencies
A_μ	Transformation matrix for analytical uncertainty propagation
$V_{\rho,\omega_0,\delta}$	Covariance matrix of the model parameters
s	Frequency analogue in the s-domain (s-transform)

A	Acceleration in the s-domain
X	Output quantity of the respective transducer in the s-domain
z^{-1}	Back shift operator used in the bilinear transform (z-transform)
T	Sampling interval
a_k	Measured input acceleration sample at the time step k
x_k	Measured accelerometer output sample at the time step k
b, c_1, c_2, Λ	Model parameters in the case of discretized time domain data
v	Substitutional parameters for the time domain parameter estimation
$\hat{v}$	Estimates of v by weighted least squares fitting
$V_{\hat{v}}$	Covariance matrix of the estimated parameters $\hat{v}$
Ω	Circular frequency normalized to the sample rate
χ^2	Sum of weighted squared residuals
y_k	Calculated transducer output for the time step k based on estimated parameters
$\hat{b}, \hat{c}$	Best estimates of b and c (see 9.2)

5 Consideration of typical frequency response and transient excitation

A typical acceleration transducer has a complex frequency response. This is usually given in terms of magnitude and phase with a shape, as shown in Figure 1. The magnitude is given in arbitrary units (a.u.).

This response function is subsequently sampled with lowest uncertainties by a calibration method in accordance with ISO 16063-11 or ISO 16063-21 making use of periodic excitation.

In applications with transient input signals, the transducer is then exposed to broadband excitation in terms of the frequency domain. The response in this case cannot be calculated with the help of a single (complex) value like the transfer sensitivity. Rather, the response can be considered to be a sensitivity that is weighted by those components in the frequency response that are excited by the spectral contents of the input signal.

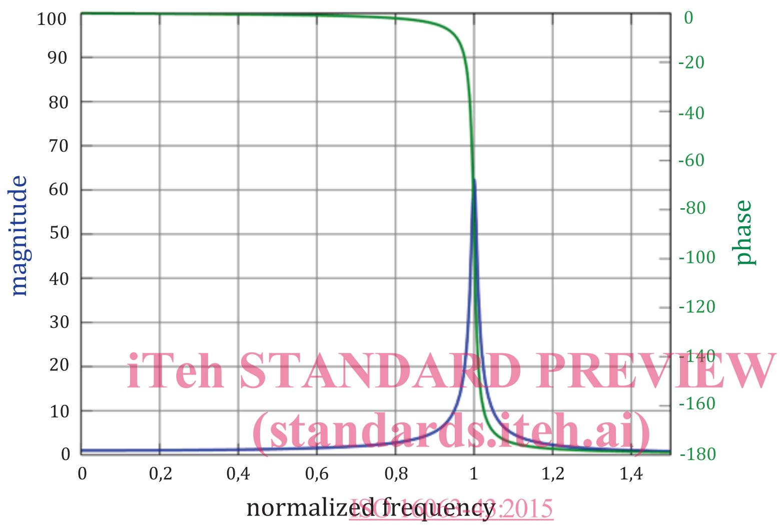
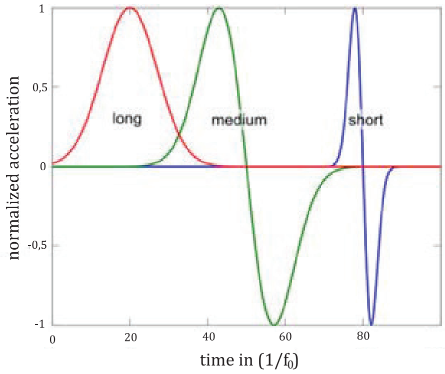
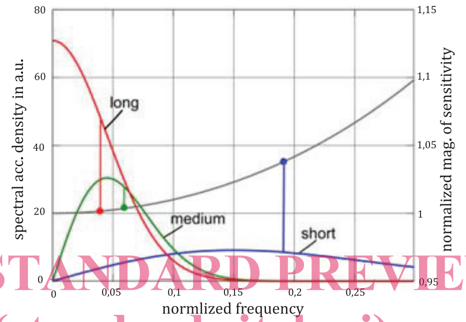


Figure 1 — Complex frequency response of a typical accelerometer in terms of magnitude of sensitivity (blue) and phase delay (green) over the normalized frequency

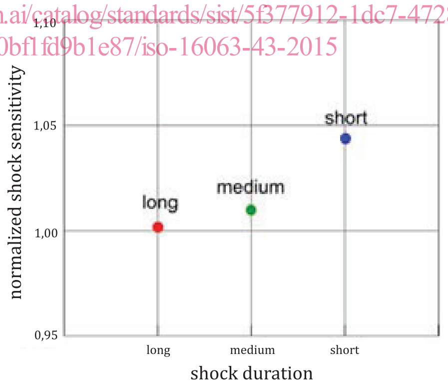
Figure 2 gives a pictorial representation of three examples of possible shock excitation signals and their respective spectra as compared to the frequency response of a typical transducer. It shows the projection of the centre of mass of the magnitude of the spectral density curve onto the sensitivity curve of a typical accelerometer. This demonstrates that a single value characterization of a transducer by shock calibration cannot sufficiently describe the dynamic behaviour.



a) Time domain representation of a long monopole (red), medium dipole (green), and short dipole (blue) shock



b) Frequency domain representation (magnitude) with the projection of the spectral centre point onto the sensitivity curve of a typical accelerometer response



c) Corresponding shock sensitivity (peak ratio) of a typical accelerometer

Figure 2 — Comparison of the characteristics of three different shock signals