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Methods for the calibration of vibration and shock transducers —

Part 16: Calibration by Earth's gravitation

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

Partie 16: Étalonnage par gravitation tellurique

Reference number
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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 on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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 first edition of ISO 16063-16 cancels and replaces the first edition of ISO 5347-5:1993, 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 15: Primary angular vibration calibration by laser interferometry*

— *Part 16: Calibration by Earth's gravitation*

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

— *Part 22: Shock calibration by comparison to a reference transducer*

— *Part 31: Testing of transverse vibration sensitivity*

— *Part 41: Calibration of laser vibrometers*

The following parts are under preparation:

— *Part 32: Resonance testing — Testing the frequency and the phase response of accelerometers by means of shock excitation*

— *Part 33: Testing of magnetic field sensitivity*

— *Part 42: Calibration of seismometers with high accuracy using acceleration of gravity*

Methods for the calibration of vibration and shock transducers —

Part 16: Calibration by Earth's gravitation

1 Scope

This part of ISO 16063 specifies the instrumentation and procedure to be used for performing primary calibration of accelerometers using Earth's gravitation. It is applicable to rectilinear accelerometers with DC (zero hertz frequency) response, such as straingauge, piezoresistive, variable capacitance, and servo accelerometer types.

This part of ISO 16063 is applicable to the calibration of the magnitude of the sensitivity, referenced to the acceleration due to the local gravitation at 0 Hz.

With the use of appropriate calibration equipment, this part of ISO 16063 can be applied to the calibration of the magnitude of the sensitivity, referenced to fractional parts of the acceleration due to the local gravitation at 0 Hz. The specification of the instrumentation used contains requirements on environmental conditions, as well as specific requirements for the apparatus to be used.

The sensitivity obtained using this part of the ISO 16063 standard for accelerometers with a DC response can be used over the flat part of the low-frequency range of the accelerometer. The degree of flatness of the applicable frequency range is intended to be taken into account in the uncertainty of measurement (UoM).

This part of ISO 16063 is applicable to reference standard accelerometers and working standard accelerometers, as well as complete acceleration measurement chain (accelerometer complete with amplifier and readout unit).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

3 Uncertainty of measurement

All users of this part of ISO 16063 are expected to make an uncertainty budget according to Annex A in order for them to document their UoM estimation. A calibration arrangement example is given in order to help set up systems that fulfil different uncertainty requirements.

When the local value of acceleration due to gravitation, g_l, is known and used, an UoM of 0,1 % can be obtained.

When the local value of acceleration due to gravitation, g_l, is not known and the standard acceleration due to gravitation, g_n, is used (ignoring the influence of latitude and altitude), an UoM of 0,5 % can be obtained. This estimation is assuming a value for the acceleration due to Earth's gravitation of 9,806 65 m/s^2 ± 0,026 m/s^2.

The uncertainty limits mentioned in this clause are applicable to devices with a maximum transverse sensitivity of 5 %.

A more detailed description of the uncertainty components is given in Annex A.

The uncertainty of measurement is expressed as the expanded measurement uncertainty in accordance with ISO 16063-1 (referred to in short as uncertainty).

4 Requirements for apparatus and other conditions

4.1 General

This clause gives recommended specifications for the apparatus necessary to fulfil the scope of Clause 1 and to obtain the uncertainties of Clause 3, if the recommended specifications listed below are met for each item.

It is mandatory to document the expanded uncertainty using the methods of Annex A.

4.2 Environmental conditions

The calibration shall be carried out under the following ambient conditions:

a) room temperature: (23 ± 3) °C;

b) relative humidity: maximum 75 % RH.

Care shall be taken that external vibration and noise do not affect the quality of the measurements.

4.3 Mounting platform

The mounting platform shall be arranged so that it is possible to rotate and align the geometric axis of sensitivity of the accelerometer from 0° to 180° relative to the direction of the gravitational acceleration vector.

At the measurement positions, the platform angle in all directions shall be within ±0,1° relative to the vertical plane.

For performing measurements at positions that equal fractions of local gravity (mounting angle >0° and <180°), the preferred orientation angles in accordance with Table 1 shall be used:

Table 1 — Preferred orientation angles

Orientation angle θ	Magnitude of acceleration due to local gravity
−30° and +30° +150° and + 210°	$0{,}866\,0 \cdot g_l$
−45° and +45° +135° and +225°	$0{,}707\,1 \cdot g_l$
±60° +120° and 240°	$0{,}500\,0 \cdot g_l$

$$a_\theta = g_l \cdot \cos(\theta) \qquad (1)$$

where

a_θ is the magnitude of acceleration due to local gravity with the accelerometer mounted at a known angle, in metres per second squared;

θ is the accelerometer mounted angle, in degrees;

g_l is the magnitude for the acceleration due to local gravitation, in metres per second squared.

4.4 Accelerometer output measuring instrumentation

A voltage measuring instrument, measuring the output from the accelerometer, having the following characteristics shall be used:

a) Frequency: 0 Hz (DC voltage);

b) Maximum uncertainty: 0,05 % of reading.

4.5 Earth's gravitation

The positive and negative magnitudes for the acceleration due to local gravity, expressed in metres per second squared (m/s^2), shall be used.

The value of the local magnitude of acceleration due to gravity, g_l, can be determined by measurement with absolute or relative gravimeters[17] or by use of geodetic formulae[16] or survey.

$$g_l\,(\varnothing,\mathrm{H}) = 9{,}780\,318\,4\,[1 + 0{,}005\,302\,4\,\sin^2(\varnothing) - 0{,}000\,005\,9\,\sin^2(2\varnothing)] - 0{,}000\,003\,086H \qquad (2)$$

where

g_l is the magnitude for the acceleration due to gravitation at the given latitude and elevation, in metres per second squared;

$\varnothing$ is the given latitude, in radians;

H is the given altitude, in metres above sea level.

Using Formula (2), g_l can be determined with an uncertainty of 0,01 % (k = 1).

If the magnitude for the acceleration due to local gravity is not known, then the standard acceleration due to gravity, g_n, shall be used:

$$g_n = 9{,}806\,65\ \mathrm{m/s^2}\ [10] \qquad [3]$$

5 Method

5.1 General

As the acceleration due to gravitation varies with location and altitude (typical values of acceleration due to local gravity at the locations of metrology institutes are within the range of 9,78 m/s^2 to 9,83 m/s^2), the local value with four significant digits shall be used.

5.2 Test procedure for 0° and 180°

Set the geometric axis of sensitivity of the accelerometer to 0° with the gravitational acceleration vector and record the accelerometer output voltage, u_0. Rotate the mounting platform so as to position the geometric axis of sensitivity of the accelerometer to 180° relative to the gravitational acceleration vector. Record the accelerometer output voltage, u_{180}.

Calculate the accelerometer sensitivity, S_g, in volts per metre per second squared (V/(m/s^2) using Formula (4):

$$S_g = \frac{u_0 - u_{180}}{2 \cdot g} \tag{4}$$

where

u_0 is the value for accelerometer output voltage (V), measured at the first extremity of rotation (0°);

u_{180} is the value for accelerometer output voltage (V), measured at the second extremity of rotation (180°);

g is the magnitude for the acceleration due to gravitation that is applied in laboratory (g_n or g_l), in metres per second squared.

5.3 Test procedure for fractions of gravitation

Set the geometric axis of sensitivity of the accelerometer to $+\alpha$ and $-\alpha$ relative to the vertical plane and record the accelerometer output voltages, $u_{+\alpha}$ and $u_{-\alpha}$, after sufficient settling time. Rotate the mounting platform so as to position the geometric axis of sensitivity of the accelerometer to 180° + α and 180° - α relative to the vertical plane. Record the accelerometer output voltages, $u_{180+\alpha}$ and $u_{180-\alpha}$, after sufficient settling time.

Calculate the accelerometer sensitivity, S_g, in volts per metre per second squared [V/(m/s^2)] using Formula (5):

$$S_g = \frac{u_{+\alpha} + u_{-\alpha} + u_{180+\alpha} + u_{180-\alpha}}{4 \cdot g \cdot \cos\alpha} \tag{5}$$

where

S_g	is the accelerometer sensitivity calibrated at an acceleration equal to (g·cos α);
$u_{+\alpha}$	is the value for the accelerometer output at the first geometric axis of rotation (+α), in volts (V);
$u_{-\alpha}$	is the value for accelerometer output at the forth geometric axis of rotation (−α), in volts (V);
$u_{180+\alpha}$	is the value for accelerometer output at the second geometric axis of rotation 180° − α, in volts (V);
$u_{180-\alpha}$	is the value for accelerometer output at the third geometric axis of rotation 180 + α, in volts (V);
g	is the magnitude of the acceleration due to gravitation that is applied in the laboratory (g_n or g_l), in metres per second squared (m/s^2);
α	is the angle between the gravitational vector and the geometric axis of sensitivity of the accelerometer, in degrees (°).

5.4 DC offset consideration

A characteristic property for an accelerometer with DC response is the DC offset voltage under the condition of zero acceleration input, u_{a0}. For instance, the DC offset parameter is of importance for applications that require integration of the accelerometer output voltage.

The total output voltage, u, of the accelerometer is:

$$u = S \cdot a + u_{a0} \tag{6}$$

where

u	is the accelerometer output voltage;
S	is the accelerometer sensitivity;
a	is the acceleration;
u_{a0}	is the zero measured output voltage.

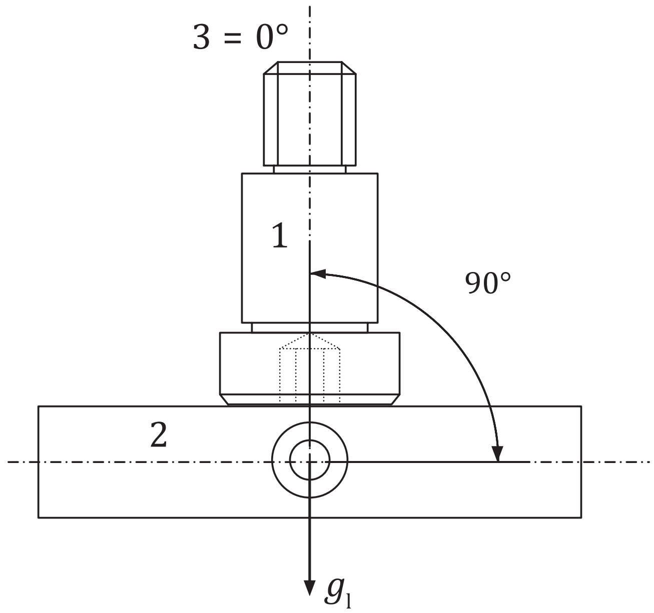
If both cross axis sensitivity and non-linearity are zero then u_{a0} can be determined by:

$$u_{a0} = u_{\alpha 0} - S_g \times g = u_{\alpha 180} + S_g + g \qquad (7)$$

where

- u_{a0} is the accelerometer output voltage at zero acceleration;
- S_g is the accelerometer sensitivity;
- g is the magnitude of the acceleration due to gravitation that is applied in the laboratory (g_{n} or g_{l}), in metres per second squared (m/s^2);
- $a_{\alpha 0}$ is the acceleration with the accelerometer mounted at 0° angle;
- u_{a0} is the measured output voltage with the accelerometer mounted at 0° angle;
- $a_{\alpha 180}$ is the acceleration with the accelerometer mounted at 180° angle;
- u_{a180} is the measured output voltage with the accelerometer mounted at 180° angle.

5.5 Calibration setup



Key

1 accelerometer

2 mounting platform

3 angle between the gravitational vector and the geometric axis of sensitivity of the accelerometer

Figure 1 — Accelerometer setup showing 0° measurement position

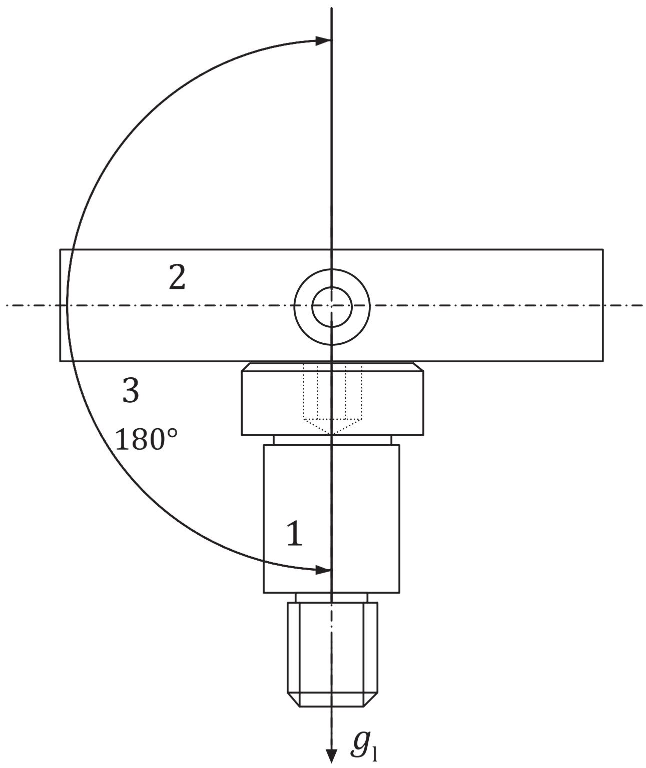


Figure 2 — Accelerometer setup showing 180° measurement position

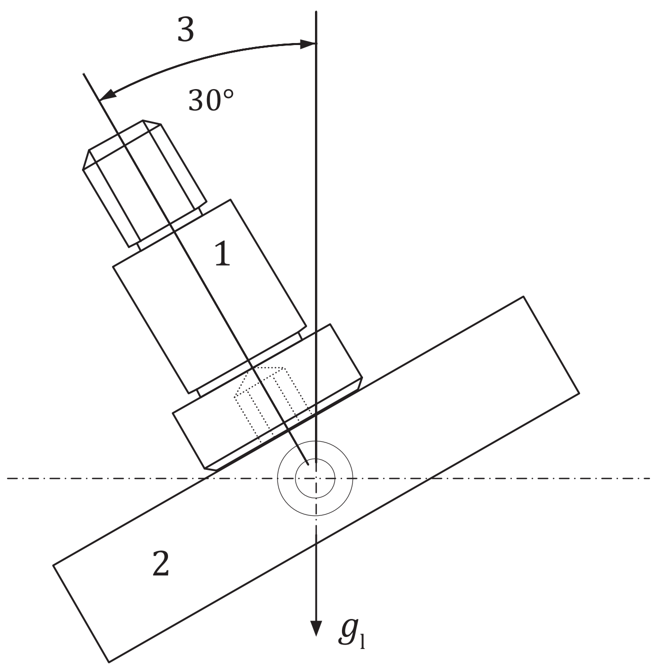


Figure 3 — Accelerometer setup showing 30° measurement position

6 Report of calibration results

When the calibration results are reported, in addition to the calibration method used, at least the following conditions and information shall be stated:

a) ambient conditions:

— ambient air temperature (°C);

— relative humidity (% RH);

— value for acceleration due to Earth's gravitation (m/s^2);

b) calibration results:

— the accelerometer sensitivity;

— the values of u_0 and u_{180} or u_α, $u_{-\alpha}$, $u_{180+\alpha}$, and $u_{180-\alpha}$;

— the expanded uncertainty of measurement with the coverage factor k (usually k = 2).

Annex A
(normative)

Uncertainty components in the calibration by gravitation

A.1 Calculation of $U_{rel}(y)$

The relative expanded uncertainty of measurement of the sensitivity, $U_{rel}(y)$, shall be calculated in accordance with ISO 16063-1 from Formulae (A.1) and (A.2):

$$U_{rel}(y) = k u_{c,rel}(y) \tag{A.1}$$

$$u_{c,rel}(y) = \frac{u_c}{y} = \frac{1}{y}\sqrt{\sum_{i=1}^{8} u^2(x_i)} \tag{A.2}$$

with the coverage factor k = 2.

where

y is the measured sensitivity;

u_i is the standard uncertainty component of index i;

$u_c(y)$ is the combined uncertainty;

$u_{c,rel}(y)$ is the combined relative uncertainty;

k is the coverage factor;

$U_{rel}(y)$ is the expanded relative uncertainty.

Table A.1 — Uncertainty components

Standard uncertainty component $u(x_i)$	**Source of uncertainty**	**Uncertainty contribution** $u_i(y)$
$u(a_g)$	acceleration magnitude due to gravitation	$u_1(S)$
$u(a_u)$	voltage measurement	$u_2(S)$
$u(r_u)$	voltage measurement resolution	$u_3(S)$
$u(a_{ST})$	transverse sensitivity	$u_4(S)$
$u(\alpha_p)$	position misalignment	$u_5(S)$
$u(e_E)$	environmental conditions on measurement (e.g. temperature)	$u_6(S)$
$u(x_{RE})$	residual sources on calibration result (e.g. random effect in repeat measurements)	$u_7(S)$

The sources of uncertainties may be subdivided and numbered in a way differing from that used in the Table A.1, provided each effect significantly influencing the measurement result has been taken into account.

The accuracy of the acceleration magnitude due to gravitation is related to the angular measurement uncertainty $u(\alpha)$ in the following form:

$$u^2(e_g)=g^2\times\sin^2(\alpha)\times u^2(\alpha)+u^2(g) \quad (A.3)$$

where

α is the direction of the geometric axis of sensitivity of the accelerometer relative to the vertical plane;

$u(\alpha)$ is the absolute standard uncertainty of the measurement of α;

$u(g)$ is the absolute standard uncertainty of the knowledge of the applied magnitude of acceleration due to gravitation (g_n or g_l).

This results in a minimum of $u^2(e_g)$ at vertical orientation (α = 0° or α = 180°) and a maximum at horizontal orientation (α = ± 90°).

For the effect of the transverse sensitivity, a similar approach has to be considered, leading to a minimum of zero at vertical orientation (α = 0° or α = 180°), as there is no transverse acceleration present and a maximum at horizontal orientation (α = ± 90°) where a maximum transverse acceleration of g is present.

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