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Vibration och stöt – Sensorer – Del 41: Kalibrering av laservibrationsmätare (ISO 16063-41:2011, IDT)

Methods for the calibration of vibration and shock transducers – Part 41: Calibration of laser vibrometers (ISO 16063-41:2011, IDT)

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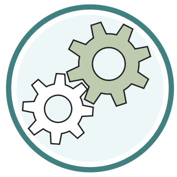

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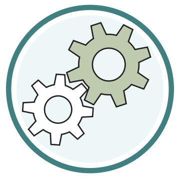

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Den internationella standarden ISO 16063-41:2011 gäller som svensk standard. Detta dokument innehåller den officiella engelska versionen av ISO 16063-41:2011.

The International Standard ISO 16063-41:2011 has the status of a Swedish Standard. This document contains the official English version of ISO 16063-41:2011.

Upplysningar om sakinnehållet i standarden lämnas av SIS, Swedish Standards Institute, telefon 08-555 520 00. Standarder kan beställas hos SIS som även lämnar allmänna upplysningar om svensk och utländsk standard.

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Denna standard är framtagen av kommittén för Vibration och stöt, SIS/TK 111.

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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 16063-41 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring, Subcommittee* SC 3, *Use and calibration of vibration and shock measuring instruments*.

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 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 16: Calibration by Earth's gravitation*

Methods for the calibration of vibration and shock transducers — Part 41: Calibration of laser vibrometers

1 Scope

This part of ISO 16063 specifies the instrumentation and procedures for performing primary and secondary calibrations of rectilinear laser vibrometers in the frequency range typically between 0,4 Hz and 50 kHz. It specifies the calibration of laser vibrometer standards designated for the calibration of either laser vibrometers or mechanical vibration transducers in accredited or non-accredited calibration laboratories, as well as the calibration of laser vibrometers by a laser vibrometer standard or by comparison to a reference transducer calibrated by laser interferometry. The specification of the instrumentation contains requirements on laser vibrometer standards.

Rectilinear laser vibrometers can be calibrated in accordance with this part of ISO 16063 if they are designed as laser optical transducers with, or without, an indicating instrument to sense the motion quantities of displacement or velocity, and to transform them into proportional (i.e. time-dependent) electrical output signals. These output signals are typically digital for laser vibrometer standards and usually analogue for laser vibrometers. The output signal or the reading of a laser vibrometer can be the amplitude and, in addition, occasionally the phase shift of the motion quantity (acceleration included). In this part of ISO 16063, the calibration of the modulus of complex sensitivity is explicitly specified (phase calibration is provided in Annex D).

NOTE Laser vibrometers are available for measuring vibrations having frequencies in the megahertz and gigahertz ranges. To date, vibration exciters are not available for generating such high frequencies. The calibration of these laser vibrometers can be estimated by the electrical calibration of their signal processing subsystems utilizing appropriate synthetic Doppler signals under the following preconditions:

— the optical subsystem of the laser vibrometer to be calibrated has been proven to comply with defined requirements comparable to those given in 5.5.3;

— synthetic Doppler signals are generated as an equivalent substitute for the output of the photodetectors.

More detailed specifications of this approach (see Reference [25]) lie outside the scope of this part of ISO 16063.

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 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers*

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*

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

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

3 Classification of laser vibrometers and principles of test methods

3.1 Classification of laser vibrometers

3.1.1 A **laser vibrometer standard** (LVS) is a reference standard containing a laser interferometer, designed and intended to serve as a reference to calibrate laser vibrometers and/or vibration transducers.

NOTE Methods 1, 2, and 3 are applicable to the primary calibration of LVSs.

3.1.2 A **laser vibrometer** (LV) is a measuring instrument containing a laser interferometer, designed and intended to perform vibration measurements.

NOTE Methods 1, 2, and 3 are applicable to the primary calibration of LVs, and method 4 is applicable to the secondary calibration of LVs. The reference accelerometer used for method 4 is calibrated by method 1, 2 or 3. For specific requirements, see 5.11.

3.1.3 A **laser optical transducer** is a measurement transducer sensing, by laser light, the motion quantities of displacement or velocity and transforming these quantities into a proportional time-dependent output signal.

3.2 Principles of test methods

3.2.1 General. Four methods are specified in analogy to ISO 16063-11 (laser interferometry) and ISO 16063-21 (comparison to a reference transducer), respectively. Methods 1, 3, and 4 provide for calibrations at preferred displacement amplitudes, velocity amplitudes and acceleration amplitudes at various frequencies. Method 2 requires calibrations at fixed displacement amplitudes (velocity amplitude and acceleration amplitude vary with frequency).

For each interferometric method specified in this part of ISO 16063 (see 3.2.2 to 3.2.4), currently a specific frequency range applies. In fact, the applicability of the particular methods mainly depends on the displacement or velocity amplitudes measurable within given measurement uncertainties. These, however, not only depend on the measurement method itself but also on the frequency-dependent properties of the vibration exciters available. Using adequate vibration exciters to generate sufficient displacement or velocity amplitudes, the upper frequency limits of all methods can be expanded to 100 kHz and even beyond. The primary method 3 (see 3.2.4) and the comparison method 4 (see 3.2.5) are applicable at frequencies lower than 0,4 Hz.

3.2.2 Method 1, the **fringe-counting method**, is a vibration measurement method using a homodyne interferometer with a single output (see Note 2) in conjunction with instrumentation for fringe counting of the interferometer signal. Considering that the displacement corresponding to the distance between two fringes (intensity maxima or intensity minima) is given by half the wavelength of the principal lines in the emission spectrum of neon of the He-Ne laser, the displacement amplitude can be calculated from the number of fringes counted during a given number (e.g. 1 000) of vibration periods.

For details, see Clause 8 and, for further information, ISO 16063-11:1999, B.1.

NOTE 1 Method 1 is applicable to the primary calibration of the laser vibrometer (modulus only) in the frequency range 1 Hz to 800 Hz and, under special conditions, at lower and higher frequencies. In Reference [26], the applicability of method 1 has been demonstrated at frequencies up to 347 kHz.

NOTE 2 Alternatively, the homodyne interferometer signal from one of the two outputs of a quadrature interferometer can be used.

NOTE 3 The electronic fringe counting can be substituted by the signal coincidence method (see References [1] [23] [24]), which indicates a displacement amplitude of a quarter wavelength, $\lambda/4$, of the laser light (158,2 nm for a red helium-neon laser). In the general case, the interferometer signal shows relative maxima and minima at the times when the vibration displacement approaches its positive and negative peak values, respectively. In the discrete case (158,2 nm), the relative signal maxima and minima approach the same signal level from the negative and positive directions, respectively ("coincidence"). By observing the interferometer signal as a function of time on an oscilloscope and adjusting the vibration amplitude to the level where a bright sharp line appears, the discrete amplitude (158,2 nm) is identified. The bright line varies with time as the initial phase of the interferometer signal varies due to low-frequency motion. In Reference [26], the applicability of the signal coincidence method has been demonstrated at frequencies up to 160 kHz.

3.2.3 **Method 2**, the **minimum-point method**, is a vibration measurement method using a homodyne interferometer with a single output in conjunction with instrumentation for zero-point detection of a component of the frequency spectrum of the interferometer signal. Considering the frequency spectrum of the intensity and adjusting the vibration amplitude to the level at which the component of the same frequency as the vibration frequency is zero, the displacement amplitude can be calculated from the argument corresponding to the respective zero point of the Bessel function of the first kind and first order.

For details, see Clause 9 and, for further information, ISO 16063-11:1999, B.2.

NOTE 1 Method 2 can be used for modulus calibration in the frequency range 800 Hz to 10 kHz with an electro-dynamic vibration exciter, and up to 50 kHz and higher with a vibration exciter for large vibration amplitudes, preferably a piezo-electric vibration exciter. In Reference [27], the applicability of method 2 has been demonstrated at frequencies up to 50 kHz.

NOTE 2 For displacement amplitudes smaller than that of the first minimum point (193 nm for the J_1 Bessel function, 121 nm for the J_0 Bessel function), the Bessel function ratio method (e.g. see Reference [22]) can be applied if the uncertainty requirements of Clause 4 are complied with.

3.2.4 **Method 3**, the **sine-approximation method**, is a vibration measurement method using a homodyne or heterodyne interferometer with two electrical outputs in quadrature (i.e. phase-shifted by 90°) in conjunction with instrumentation for signal sampling and processing. A sine approximation of an equidistant sequence of calculated displacement or velocity values leads to the amplitude and the initial phase shift of the respective vibration quantity.

For details, see Clause 10 and, for further information, ISO 16063-11:1999, B.3.

NOTE Method 3 can be used for modulus and phase calibration if the laser vibrometer provides both measurement capabilities. Method 3 in the homodyne or heterodyne interferometer version provides calibrations in the frequency range 0,4 Hz to 50 kHz or wider. In Reference [26], the applicability of method 3 has been demonstrated at frequencies up to 347 kHz.

3.2.5 **Method 4**, the **comparison to a reference transducer**, is a vibration measurement method using a reference accelerometer calibrated by a suitable primary method (laser interferometry) or secondary method (comparison to a reference transducer), see 5.11. The acceleration amplitude, $\hat{a}$, is calculated using the equation

$$\hat{a} = \frac{1}{S_{a,\mathrm{R}}} \hat{u}$$

where

$S_{a,\mathrm{R}}$ is the acceleration sensitivity (magnitude) of the reference accelerometer;

$\hat{u}$ is the amplitude of the accelerometer output during laser vibrometer calibration.

For the calculation of the displacement and velocity amplitudes and other details, see Clause 11.

NOTE 1 Method 4 is applicable to the calibration of laser vibrometers (magnitude and phase) in a frequency range 0,4 Hz to 50 kHz or wider. For frequencies higher than 5 kHz, the reference transducer shall be calibrated by laser interferometry (see 5.11). The frequency range of method 4 is limited to the frequency range over which the reference transducer was calibrated.

NOTE 2 Vibration calibration of transducers by comparison to a reference transducer is specified in detail in ISO 16063-21. The same method can be used for calibration of laser vibrometers operated as laser optical transducers (see 3.1.3).

4 Uncertainty of measurement

All users of this part of ISO 16063 are expected to make uncertainty budgets in accordance with Annex A to document their uncertainty.

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

As this part of ISO 16063 covers three measurands (displacement, velocity and acceleration) in wide amplitude and frequency ranges with different accuracy requirements and different performances of the devices to be calibrated (laser vibrometer standards and laser vibrometers), the uncertainty of measurement may range from small to relatively large values. 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.

Two examples are given in order to help set up systems that fulfil different uncertainty requirements. System requirements for each are set up and the attainable uncertainty is given. Example 1 is applicable to calibrations performed under well-controlled laboratory conditions resulting in relatively small uncertainties. Example 2 is applicable to calibrations in which relatively large uncertainties can be accepted or where calibration conditions are such that only less narrow tolerances can be maintained. These two examples are used throughout this part of ISO 16063.

EXAMPLE 1 A laser vibrometer standard is calibrated by primary means (method 1, 2 or 3 as specified in this part of ISO 16063) with documented small uncertainty. The temperature and other conditions are kept within narrow limits during the calibration as indicated in the appropriate clauses.

Figures 1 to 4 show examples for the calibration equipment applicable to fulfil high accuracy requirements represented by Example 1.

EXAMPLE 2 A laser vibrometer is calibrated using a laser vibrometer standard calibrated according to Example 1.

For both examples, the minimum calibration requirement on the reference transducer is a calibration at suitable reference conditions (i.e. frequency, amplitude and temperature). Normally, the conditions are chosen as indicated in Clause 5.

The typical attainable uncertainties specified in Table 3 are applicable for the parameters specified in Table 1.

Table 1 — Typical frequency and amplitude ranges of displacement, velocity and acceleration

Frequency range:	0,4 Hz to 50 kHz
Dynamic range (amplitude):	
• displacement	• 1 nm to 1 m
• velocity	• 0,1 mm/s to 1 m/s (frequency-dependent)
• acceleration	• 0,1 m/s^2 to 20 km/s^2 (frequency-dependent)

NOTE The indicated ranges are not mandatory, and calibrations performed at a single point or in smaller ranges of frequency, amplitude or both are also acceptable.

At any given frequency and amplitude of acceleration, velocity or displacement, the dynamic range is limited by the noise floor and the amount of distortion produced by the vibration generation equipment (if no filtering is used) or its maximum power. In the case of spring-controlled vibration exciters, specific techniques may be used to compensate for inherent distortion occurring at large displacements by using an appropriate non-sinusoidal voltage at the input of the power amplifier. Typical frequency ranges and maximum vibration amplitude ranges of electro-dynamic and piezo-electric vibration exciters are given in 5.3.

The uncertainty components of the calibration methods characterized in Table 2 are specified in Annex A.

Table 2 — Applicability of calibration methods influencing the uncertainty of measurement

Marking of method	Characterization of method (Optical transducer/signal treatment)
Method 1	Homodyne interferometer (single output signal/fringe counting)
Method 2	Homodyne interferometer (single output signal/spectral analysis)
Method 3 (homodyne)	Homodyne interferometer (two output signals in quadrature/sine approximation)
Method 3 (heterodyne)	Heterodyne interferometer (output with frequency offset/sine approximation)
Method 4	Comparison to a reference transducer calibrated by method 1, 2 or 3

NOTE 2 Calibrations shall be traceable to a national measurement standard of the SI unit of acceleration, velocity or displacement and be performed by a competent laboratory, e.g. one that is in compliance with ISO/IEC 17025 (Reference [21]).

Typical uncertainties that are attainable for Example 1 and Example 2 given above are specified in Table 3. In practice, these uncertainty values may be exceeded or even smaller uncertainties may be achieved depending on the performance of the calibration apparatus and the quantities influencing the calibration result. It is the responsibility of the laboratory or end user to make sure that the reported values of expanded uncertainty are credible. This can be achieved by evaluating the expanded measurement uncertainty in accordance with Annex A and ISO 16063-1:1998, Annex A.

Table 3 — Typical attainable uncertainties

Frequency range	Example 1	Example 2
0,4 Hz to <1 Hz	0,25 %	1 %
1 Hz to 5 kHz	0,25 %	0,5 %
>5 kHz to 10 kHz	0,3 %	1 %
>10 kHz to 20 kHz	0,5 %	3 %
>20 kHz to 50 kHz	1 %	5 %

NOTE The expanded uncertainties given as examples (e.g. 0,5 % at 20 kHz) are based on concrete uncertainty budgets established in accordance with Annex A.