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Methods for the calibration of vibration and shock transducers —

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

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

Partie 13: Étalonnage primaire de chocs par interférométrie laser

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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 3.

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 part of ISO 16063 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 16063-13 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, 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 21: Secondary vibration calibration by comparison*

Annex A forms a normative part of this part of ISO 16063. Annexes B and C are for information only.

Introduction

The shock sensitivity S_{sh} is determined, according to definition, as the relationship between the peak values of the accelerometer output quantity and the acceleration. S_{sh} is not a unique quantity but may vary depending on the duration and shape of the shock pulse and the bandwidth over which the sensitivity of the transducer under test and the frequency response of the optional conditioning amplifier are sufficiently uniform.

A unique quantity applicable for linearity tests of accelerometers is the complex sensitivity at a frequency f_n, calculated in the frequency domain. This part of ISO 16063 makes use of data-processing procedures which allow the magnitude S_n and phase shift $\Delta\varphi_n$ of the complex sensitivity to be calculated, in addition or alternatively to the shock sensitivity S_{sh} (cf. informative annex C).

The method specified in this part of ISO 16063 is based on the absolute measurement of the time history of the motion. This method fundamentally deviates from another shock calibration method which is based on the principle of the change in velocity, described in ISO 16063-1. The shock sensitivity therefore differs fundamentally from the shock calibration factor obtained by the latter method, but is in compliance with the calibration factor stated in ISO 5347-4[1].

1) To be revised as ISO 16063-22.

Methods for the calibration of vibration and shock transducers —

Part 13:
Primary shock calibration using laser interferometry

1 Scope

This part of ISO 16063 specifies the instrumentation and procedure to be used for primary shock calibration of rectilinear accelerometers, using laser interferometry to sense the time-dependent displacement during the shock. The method is applicable in a shock pulse duration range 0,05 ms to 10 ms and a range of peak values of 10^2 m/s^2 to 10^5 m/s^2 (pulse-duration dependent). The method allows the shock sensitivity to be obtained.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 16063. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 16063 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 5347-22, *Methods for the calibration of vibration and shock pick-ups — Part 22: Accelerometer resonance testing — General methods*

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

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

3 Uncertainty of measurement

The limits of the uncertainty of shock sensitivity measurement shall be as follows:

— 1 % of the reading at a reference peak value of 1 000 m/s^2 and reference shock pulse duration of 2 ms and reference amplifier gain settings;

— $\leqslant$ 2 % for all values of peak acceleration and shock pulse duration.

The uncertainty specifications above are valid for the calibration of acceptable precision-grade transducers (e.g. reference standard accelerometers) provided that great care is taken to keep all uncertainty components small enough to comply with the specifications (for uncertainty budgets, see annex A). In particular, the spectral energy produced by the excitation of any mode of resonance inherent in the transducer or shock machine structure during calibration must be small relative to the spectral energy contained in the frequency range of calibration. The transducer resonance testing shall be performed in accordance with ISO 5347-22. In general, this requirement might preclude the use of pulses with relatively short durations that are given in clauses 1 and 6.

All users of this part of ISO 16063 shall make uncertainty budgets according to annex A to document their level of uncertainty.

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

4 Requirements for apparatus

4.1 General

This clause gives specifications for the apparatus necessary to fulfil the scope of clause 1 and to obtain the uncertainties of clause 3.

4.2 Shock machine based on rigid body motion of an anvil

The shock machine shall be operated with a hammer (projectile) which shall be permitted to move and strike an anvil (target) to which the accelerometer is attached. The hammer shall impart a motion to the anvil which shall be permitted to accelerate freely and rectilinearly while the hammer shall be automatically caught. Steel springs or cushioning pads made of rubber, paper or another pulse-forming material shall be placed between the hammer and the anvil to obtain the desired pulse duration and shape. The shock pulses obtained shall have a shape approximating a half-sine, half-sine squared or Gaussian acceleration shape. The resonance frequencies of the hammer and the anvil shall be at least $10/T$, where T is the pulse duration.

In order to avoid influences from resonances in the shock machine structure, the hammer and the anvil shall operate largely isolated from the structure. The hammer and the anvil shall be aligned with a maximum distance of $\pm$ 0,2 mm between the two centrelines. The anvil shall be supported in such a way that no unsymmetric forces cause rotation and deviations from rectilinear motion.

The surface on which the accelerometer 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 at a distance apart of 5 µm, over the area corresponding to the maximum mounting surface of any transducer to be calibrated.

The drilled and tapped hole for connecting the accelerometer shall have a perpendicular tolerance to the surface of $<$ 10 µm; i.e. the centreline of the hole shall be contained in a cylindrical zone of 10 µm diameter and a height equal to the hole depth.

NOTE 1 The above requirements can be fulfilled when the anvil or both the anvil and the hammer is (are) equipped with air bearings (cf. Figure 1 and reference [1]). The shock machine shown in Figure 1 allows impulses of a half-sine squared acceleration shape to be generated [6].

NOTE 2 Some conventional shock machines used in comparison shock calibrations in accordance with ISO 5347-4 (cf. [2] and [3]) may not cause a motion which can be accurately measured by laser interferometry.

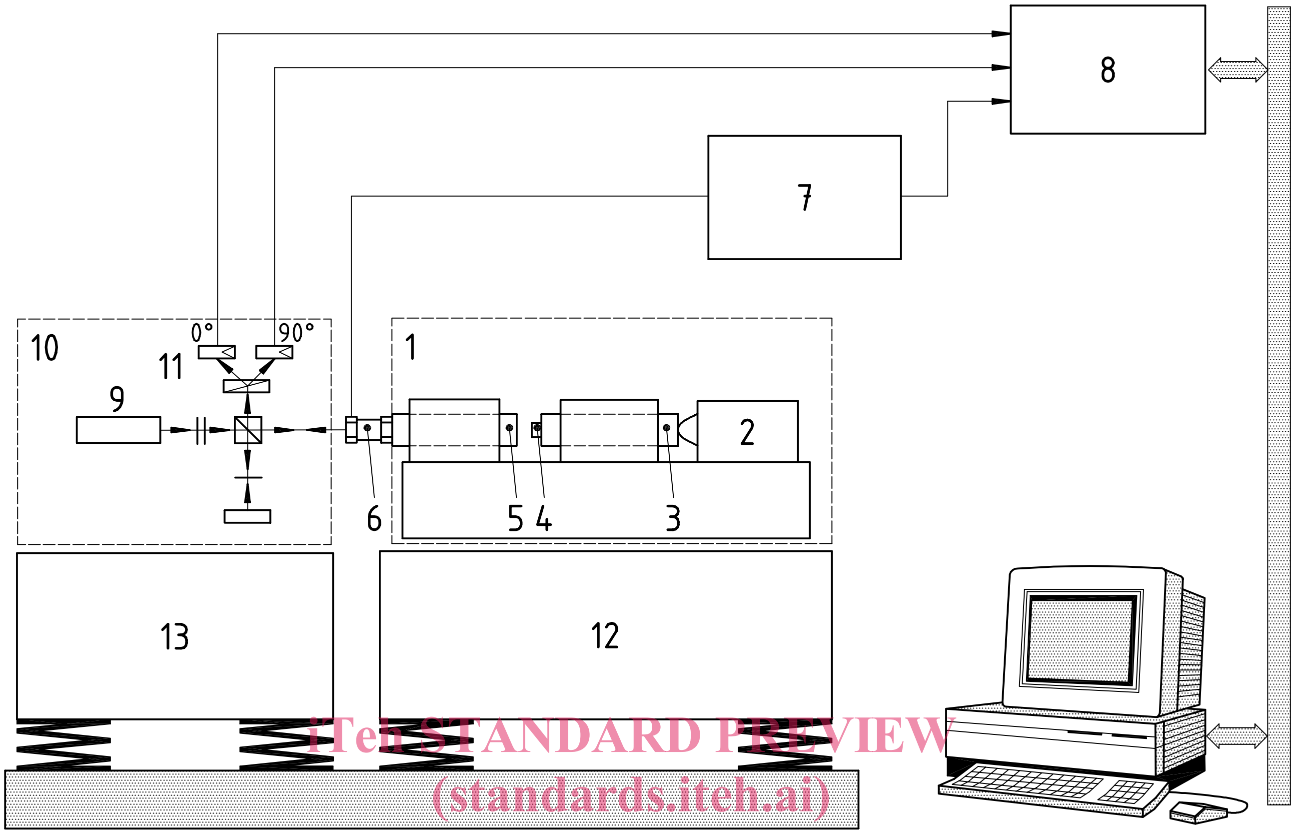
4.3 Shock machine based on wave propagation inside a long thin bar

The shock machine shall consist mainly of a movable element [e.g. a steel ball (projectile)] which shall be accelerated to strike a mitigating element (e.g. a steel ball of the same diameter) attached to a bar on which the accelerometer shall be mounted at the opposite end surface. The bar shall be flexibly supported in such a way that influences from resonances in the shock machine structure are avoided. The hammer and the anvil bar shall be aligned sufficiently to meet the uncertainty requirements of clause 3.

Any deviations from the rectilinear motion of the accelerometer's mounting surface shall be so small, at least during the measurement period which is significant for the data acquisition (maximum: 1 ms), that the stated uncertainty in calibration can be achieved. The shock machine shall be provided with a facility for triggering the data acquisition process.

The surface on which the accelerometer 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 at a distance apart of 5 µm, over the area corresponding to the maximum mounting surface of any transducer to be calibrated.



Key

1 Shock machine (4.2)
2 Spring unit
3 Airborne hammer (e.g. steel, diameter 30 mm, length 200 mm)
4 Pad
5 Airborne anvil (e.g. steel, diameter 30 mm, length 200 mm)
6 Accelerometer
7 Amplifier
8 Digital waveform recorder (4.8)
9 Laser (4.5)
10 Interferometer (4.6)
11 Light detectors (4.6)
12 1st seismic block (4.4)
13 2nd seismic block (4.4)

Figure 1 — Example of a measuring system for shock calibration based on rigid body motion of an anvil (acceleration peak value range 100 m/s^2 to 5 000 m/s^2)

The drilled and tapped hole for connecting the accelerometer shall have a perpendicularly tolerance to the surface of $< 10\ \mu$m, i.e. the centreline of the hole shall be contained in a cylindrical zone of 10 µm diameter and a height equal to the hole depth.

The dimension of the bar (see references [4], [5]) shall take into account the fact that the end surface must be accessible to the laser light beam when an accelerometer of single-ended design is mounted for calibration, and that the period available (see below) is sufficient.

The maximum shock duration and measurement period available for data acquisition is the period from the beginning of the significant pulse to the occurrence of the pulse reflected at the mounting surface (e.g. 0,8 ms in a bar 2 m in length as shown in Figure 2).

An example of a shock machine based on elastic wave propagation inside a long thin bar is shown in Figure 2. To derive a trigger signal, two strain gauges are applied to the opposite sides of the bar. The shock excitation arrangement with two steel balls shown in Figure 2 leads to acceleration shapes which can be described by the derivative of a Gaussian function, i.e. Gaussian velocity pulse [6]. This special arrangement gives good repeatability in repeated shock calibrations and relatively small changes of the spectral frequency content of the shock spectrum at different acceleration peak values [13]. Other bar sizes than that shown in Figure 2 may be applied in adaptation to different calibration conditions.

In general, the longitudinal displacement in the bar will vary as a complicated function of radial position and frequency depending on the material properties and diameter of the bar. This can introduce a frequency-dependent base strain to the transducer under test, increase the uncertainty in the calibration, or both.

4.4 Seismic block(s) for shock machine and laser interferometer

The shock exciter and the interferometer shall be mounted on the same heavy block or on two different heavy blocks so as to prevent relative motion due to ground motion, or to prevent the reaction of the exciter support structure from having excessive effects on the calibration results.

4.5 Laser

A laser of the red helium-neon type shall be used. Under laboratory conditions, i.e. an air pressure of 100 kPa, a temperature of 23 °C and a relative humidity of 50 %, the wavelength is 0,632 81 µm.

If the laser has manual or automatic atmospheric compensation, this shall be set to zero or switched off.

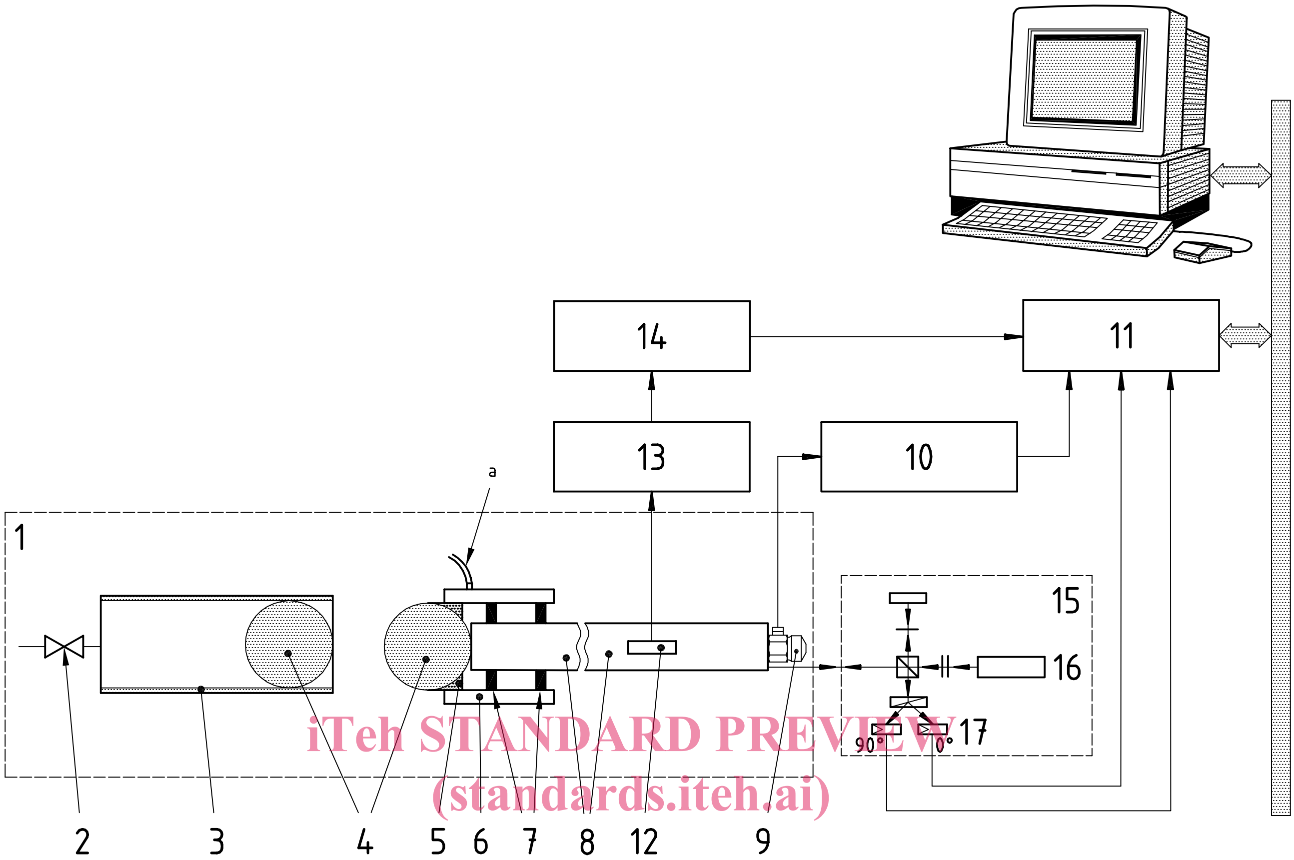
Alternatively, a single-frequency laser may be used, with another stable wavelength whose value is accurately known.

4.6 Interferometer

The interferometer shall be of a modified Michelson type, providing quadrature signal outputs, with two light detectors to sense the interferometer signal bands, and having a frequency response covering the necessary bandwidth. The required bandwidth can be calculated from the maximum velocity v_{max}, which shall be measured using the following equation:

$$f_{\text{max}} = v_{\text{max}} \times 3{,}16 \times 10^{-6}\ \text{m}^{-1}$$

The modified Michelson interferometer may be constructed according to Figure 3. A quarter-wavelength retarder converts the linearly polarized incident light into two measuring beams with perpendicular polarization states and a phase angle difference of 90°. After interfering with the linearly polarized reference beam, the two components with perpendicular polarization are separated in space by appropriate means (e.g. a Wollaston prism or a polarizing beam splitter) and detected by two photodiodes.

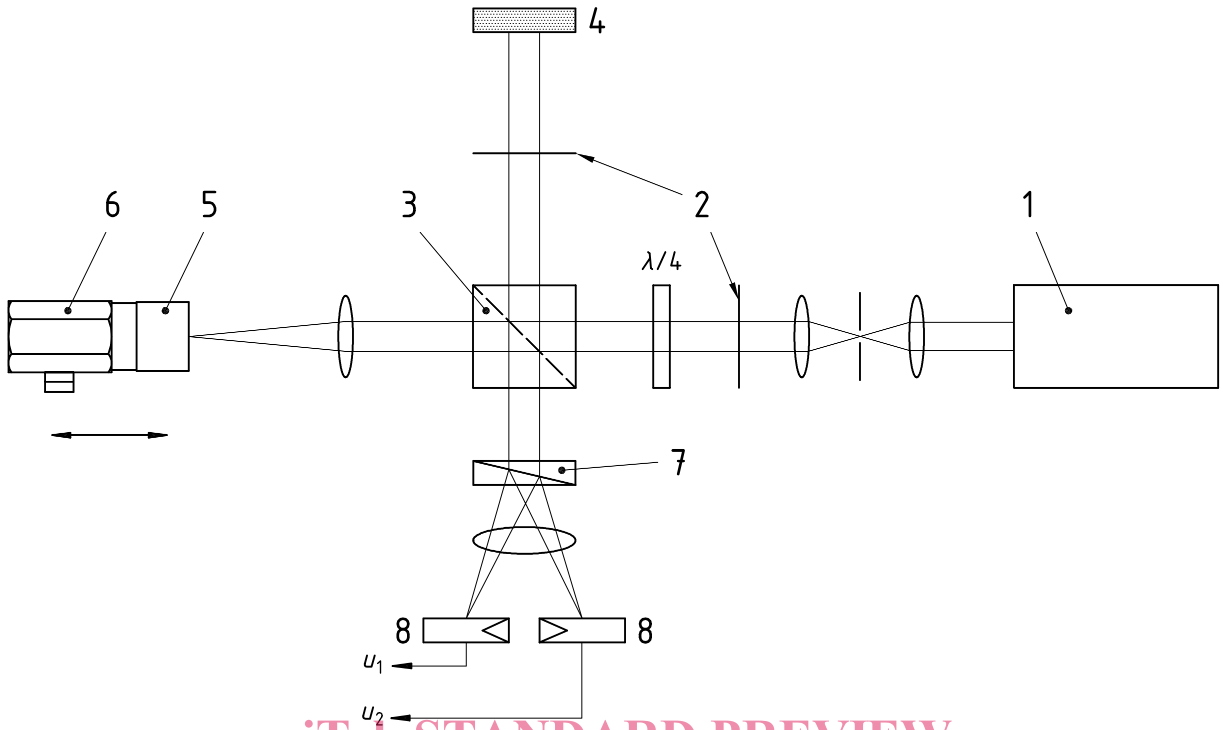


Key

1 Shock machine (4.3)
2 Valve (compressed air supply)
3 Air barrel
4 Pair of balls, of 50 mm diameter
5 Silicon rubber
6 Aluminium tube
7 O-rings
8 Bar (titanium, diameter 25 mm, length 2 000 mm)
9 Accelerometer
10 Amplifier
11 Digital waveform recorder (4.8)
12 Strain gauges
13 Bridge amplifier
14 Trigger unit
15 Interferometer (4.6)
16 Laser (4.5)
17 Light detectors (4.6)

[a] To vacuum

Figure 2 — Example of a measuring system for shock calibration based on shock propagation inside a long thin bar (acceleration peak value range 1 000 m/s^2 to 100 000 m/s^2)



Key

1	Laser
2	Polarizors
3	Beamsplitter
4	Reference mirror
5	Dummy mass (measuring reflector)
6	Accelerometer
7	Wollaston prism
8	Photodetectors

Figure 3 — Laser interferometer with quadrature output

The two outputs of the modified Michelson interferometer shall have offsets of less than ± 5 % in relation to the amplitude, relative amplitude deviations of less than ± 5 %, and deviations of less than $\pm 5^\circ$ from the nominal phase angle difference of 90°. To maintain these tolerances, appropriate means shall be provided to adjust the offset, the signal level and the angle between the two interferometer signals.

The measuring light beam from the interferometer and the anvil bar axis shall be aligned to meet the uncertainty requirements of clause 3.

For reflection of the measuring light beam, the polished end surface of the anvil bar shall be used if the accelerometer is of single-ended design, or a polished top surface shall be used in the case of back-to-back accelerometer design. The use of a mirror shall be avoided.

At high acceleration peak values, a large bandwidth may be needed. To measure, for example, a shock of 100 000 m/s^2 peak value and 200 μs duration (for acceleration shape see 4.3), an interferometer signal frequency spectrum up to 32 MHz should be transmitted. For details, see reference [6].

The (modified) Michelson interferometer may be replaced by another suitable two-beam interferometer, e.g. a (modified) Mach-Zehnder interferometer.