INTERNATIONAL STANDARD

ISO 16063-1

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Methods for the calibration of vibration and shock transducers —

Part 1:
Basic concepts

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

Partie 1: Concepts de base

Contents

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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.

International Standard ISO 16063-1 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 16063-1 cancels and replaces ISO 5347-0:1987, of which it constitutes a minor revision. A new clause 6, new annex A, and an enlarged bibliography have been included.

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

— *Part 1: Basic concepts*

— *Part 2: Primary calibrations*

— *Part 3: Secondary calibrations*

— *Part 4: Environmental calibrations*

Parts 2 to 4 are under preparation and will consist of a revision of parts 1 to 23 of ISO 5347.

Annex A of this part of ISO 16063 is for information only.

Introduction

The calibration of vibration and shock transducers has become increasingly important as the need has grown for accurate measurements of the shocks and vibrations to which man and a wide variety of equipment are subjected in service. Several methods have been used or proposed for these calibrations and some of them are described in this part of ISO 16063. Clause 5 describes methods which have proved to be reliable means for the primary calibration of vibration and shock transducers.

Methods of calibration for both vibration and shock transducers are included in this International Standard because it has proved to be impracticable to make a distinction between transducers used in measurements of vibrations and those used in measurements of shocks.

This International Standard is limited to the calibration of acceleration, velocity and displacement transducers. It does not deal with transducers used for measurements of force, pressure or strain, even though some of these may be calibrated using similar methods. Furthermore, transducers used to measure rotational vibratory motion are also excluded because, at present, they are few in number and the calibration hardware and methods are somewhat different from those for the rectilinear transducers covered by this International Standard.

This part of ISO 16063 contains definitions and describes basic primary calibration. In addition, it describes, in general terms, various methods for the calibration of vibration and shock transducers as well as methods for measuring characteristics other than sensitivity. In order to be able to carry out a calibration with known accuracy, detailed specifications for instruments and procedures have to be laid down. Information of this kind for each method of calibration will be specified in subsequent parts of ISO 16063 (i.e. revisions of parts 1 to 23 of the ISO 5347 series).

The transducer may be calibrated as a unit by itself; it may include a cable connection and/or a conditioning device. The calibration system shall always be properly described.

A bibliography is included and the references are referred to in the text by numbers in square brackets.

Methods for the calibration of vibration and shock transducers —

Part 1
Basic concepts

1 Scope

This part of ISO 16063 describes methods for the calibration of vibration and shock transducers. It also includes methods for the measurement of characteristics in addition to the sensitivity.

One primary calibration method has been selected as the preferred method (see 5.2.1). Comparison calibration methods for vibration and shock are also described (see 5.3). More detailed descriptions are given in parts 1 to 23 of ISO 5347 (see references [1] to [22]).

This part of ISO 16063 is applicable to continuous-reading rectilinear acceleration, velocity and displacement transducers and recommends a preferred method which has proved to give reliable and reproducible results.

It is not applicable to methods for the calibration of rotational transducers.

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 1101:1983, *Technical drawings — Geometrical tolerancing — Tolerances of form, orientation, location and run-out — Generalities, definitions, symbols, indications on drawings.*

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

ISO 2954:1975, *Mechanical vibration of rotating and reciprocating machinery — Requirements for instruments for measuring vibration severity.*

GUM: *Guide to the Expression of Uncertainty in Measurement*. BIPM/IEC/IFCC/ISO/OIML/IUPAC,1995.

3 Terms and definitions

For the purposes of this part of ISO 16063, the terms and definitions given in ISO 2041, together with the following, apply.

3.1
transducer

device for converting the mechanical motion to be measured, for example acceleration in a given direction, into a quantity which may be conveniently measured or recorded

NOTE A transducer may include auxiliary equipment for amplifying, supplying necessary operating power, providing necessary circuit elements, indicating or recording its output, etc.

3.1.1
operating range

range of frequency and of amplitude for which the transducer behaves as a linear transducer within specified limits of tolerance

3.1.2
reciprocal transducer

bilateral electromechanical transducer for which the ratio of the applied current to force produced (when the transducer is restrained so the velocity is zero) equals the ratio of the applied velocity to the voltage produced (when the transducer is open-circuited so the current is zero)

EXAMPLES: Electromagnetic and piezo-electric transducers.

3.1.3
unilateral transducer

transducer employing strain gauges as sensing elements for which an electrical excitation does not cause a perceptible mechanical effect in the transducer

3.2
input signal

signal applied to the input of the transducer

EXAMPLE: The acceleration applied to the mounting surface.

3.3
output signal

signal generated by the transducer in response to a given input signal

NOTE 1 For single-ended transducers, the acceleration vector is considered positive when directed into the mounting surface of the transducer. For back-to-back reference accelerometers, the acceleration vector is considered positive when directed from the top surface into the accelerometer to be calibrated by comparison.

NOTE 2 The phase of the output quantity (e.g. voltage, charge, current, resistance, etc.) should be specified with reference to the defined positive acceleration vector or the derived quantities (velocity or displacement).

3.4
sensitivity

for a linear transducer, the ratio of the output to input during sinusoidal excitation parallel to a specified axis of sensitivity at the mounting surface

NOTE 1 In general, the sensitivity includes both amplitude and phase information and is, consequently, a complex quantity which varies with frequency.

The sinusoidal input motion may be represented by the following equations:

$$s = \hat{s}\exp\left[\mathrm{j}(\omega t + \varphi_1)\right] = \hat{s}\left[\cos(\omega t + \varphi_1) + \mathrm{j}\sin(\omega t + \varphi_1)\right] \tag{1}$$

$$v = \mathrm{j}\omega s = \hat{v}\exp\left[\mathrm{j}(\omega t + \varphi_1 + \pi/2)\right] = \hat{v}\left[\cos(\omega t + \varphi_1 + \pi/2) + \mathrm{j}\sin(\omega t + \varphi_1 + \pi/2)\right] \tag{2}$$

$$a = \mathrm{j}\omega v = \hat{a}\exp\left[\mathrm{j}(\omega t + \varphi_1 + \pi)\right] = \hat{a}\left[\cos(\omega t + \varphi_1 + \pi) + \mathrm{j}\sin(\omega t + \varphi_1 + \pi)\right] \tag{3}$$

$$u = \hat{u}\exp\left[\mathrm{j}(\omega t + \varphi_2)\right] = \hat{u}\left[\cos(\omega t + \varphi_2) + \mathrm{j}\sin(\omega t + \varphi_2)\right] \tag{4}$$

where

s is the complex quantity of the displacement;

v is the complex quantity of the velocity;

a is the complex quantity of the acceleration;

u is the complex quantity of the output;

$\hat{s}$ is the peak amplitude of sinusoidal displacement;

$\hat{v}$ is the peak amplitude of sinusoidal velocity;

$\hat{a}$ is the peak amplitude of sinusoidal acceleration;

ω is the angular frequency;

φ_1 and φ_2 are the phase angles;

t is the time;

j is the imaginary unit.

The displacement sensitivity, S_s, expressed in the units of the output signal per metre, is

$$S_s = \frac{u}{s} = \hat{S}_s \exp\left[-\mathrm{j}\left(\varphi_1 - \varphi_2\right)\right] \tag{5}$$

where

$\hat{S}_s = \frac{\hat{u}}{\hat{s}}$ is the magnitude of the displacement sensitivity;

$(\varphi_1 - \varphi_2)$ is the phase lag.

The velocity sensitivity, S_v, expressed in the units of the output signal per metre per second, is

$$S_v = \frac{u}{v} = \hat{S}_v \exp\left[-\mathrm{j}\left(\varphi_1 + \pi/2 - \varphi_2\right)\right] \tag{6}$$

where

$\hat{S}_v = \frac{\hat{u}}{\hat{v}}$ is the magnitude of the velocity sensitivity;

$(\varphi_1 + \pi/2 - \varphi_2)$ is the phase lag.

The acceleration sensitivity, S_a, expressed in the units of the output signal per metre per second squared, is

$$S_a = \frac{u}{a} = \hat{S}_a \exp\left[-\mathrm{j}\left(\varphi_1 + \pi - \varphi_2\right)\right] \tag{7}$$

where

$\hat{S}_a = \frac{\hat{u}}{\hat{a}}$ is the magnitude of the acceleration sensitivity;

$(\varphi_1 + \pi - \varphi_2)$ is the phase lag.

Usually, the displacement sensitivity is determined for a displacement transducer, the velocity sensitivity for a velocity transducer, and the acceleration sensitivity for an acceleration transducer. In general, the sensitivity magnitudes and the phase angles are functions of the frequency, $f = \omega/2\pi$.

NOTE 2 A displacement, velocity or acceleration transducer in which the corresponding sensitivity does not become zero as the frequency approaches zero is said to have a zero-frequency response (direct-current response). Sensitivity under constant acceleration corresponds to $\omega = 0$ and the phase lag is zero. Examples of transducers with zero-frequency response are acceleration transducers employing strain gauges, potentiometers, differential transformers, force-balance (servo) or variable reluctance circuits as sensing elements. Seismic self-generating transducers, such as piezo-electric and electrodynamic transducers, are examples of transducers without zero-frequency response.

3.5

transverse sensitivity ratio (TSR)

ratio of the output of a transducer, when oriented with its axis of sensitivity transverse to the direction of the input, to the output when the axis of sensitivity is aligned in the direction of the same input

3.6

vibration generator

any device for applying a controlled motion to the mounting surface of a transducer

NOTE Vibration generators are sometimes referred to as exciters or shakers.

4 Characteristics to be measured

4.1 General

The primary object of the calibration of a transducer is to determine its calibration factor (sensitivity) over the amplitude and frequency range for the degree of freedom for which the transducer is to be used. In addition, it may be important to know its response to motions in the other five degrees of freedom; for example, for a rectilinear acceleration transducer, its response should be known to motions at right angles to the sensitive direction and to rotations. Other important factors include damping, phase lag, non-linearity or variation in response with amplitude of motion, effect of temperature and pressure changes, and other extraneous conditions such as motion of the connection cable.

4.2 Direct response

4.2.1 Frequency response and phase response

The sensitivity of a transducer is obtained by placing the transducer with its sensitivity axis parallel to the direction of motion of the vibration generator, measuring the motion or input applied by the vibration generator, and measuring the output of the transducer. Both continuous-reading and peak-reading transducers can also be calibrated with a controlled transient excitation whose amplitude and frequency components are within the working range of the transducer. To detect any resonances, the output of the transducer should be observed while varying the vibration generator frequency slowly and continuously over the frequency range. In general, only information concerning magnitude sensitivity calibration is given as a function of frequency. However, for the use of a vibration transducer close to its upper or lower frequency limits, or for special applications, the phase response may be required. This is determined by measuring the phase lag between the output signal and the mechanical excitation over the frequency range of interest.

4.2.2 Non-linearity

Deviations from linearity of the output of a transducer (amplitude distortions) are determined by measuring its output magnitude as the magnitude of the input is increased from the smallest value to the largest value for which the transducer is designed. When a sinusoidal vibration generator is used, the measurement should be repeated for several frequencies.

Non-linearity may take several forms. The sensitivity of the transducer may change progressively with increasing amplitude, there may be a permanent change leading to a displacement of the zero after subjecting the transducer to vibration or shock, or there may be stops that limit the range of motion suddenly.

The type and magnitude of the non-linearity of a transducer may be indicated by its amplitude distortion and by comparing its resonance curve, its phase lag, and its decrement with the corresponding characteristics for the idealized linear transducer. The permissible deviations from linearity will depend on the measurements to be made. Non-linearity should be expected at the upper limit of the useful dynamic range of the transducer.

4.3 Spurious response

4.3.1 Temperature dependency

The sensitivity, damping ratio and resonance frequency of many transducers change as a function of temperature. Temperature response calibrations are usually performed using a comparison method. The standard transducer is mounted axially in line with the test transducer. The test transducer is placed inside a temperature chamber and the standard transducer is located outside the chamber or otherwise protected from changes in temperature in such a way that its sensitivity remains constant to within 2 % for the ambient temperatures present during the entire calibration. The vibration generator is used only at frequencies where it is known that the transverse motion is less than 25 % of the axial motion. The vibration generator is selected and a fixture designed so that there is negligible relative motion between the test and standard transducers at frequencies at which the calibration is to be performed.

An alternative procedure for performing temperature response calibrations is to mount the standard and test transducers on a suitable fixture inside the temperature chamber. This method is limited to temperature ranges over which the response of the standard transducer is known.

For transducers which respond to static acceleration, the zero unbalance is measured at the maximum and minimum temperatures.

Transducers with internal damping greater than 10 % of the critical damping should be calibrated at a minimum of four frequencies at a single vibration amplitude and at each of four temperatures in addition to room temperature. This method is equally applicable to transducers, such as the electrodynamic types, which utilize a coil of wire in their operation. The frequencies are selected throughout the frequency range of intended use.

The internal capacitance and resistance of piezo-electric transducers shall be measured after stabilization at the maximum calibration temperature.

If the measured resistance of a piezo-electric accelerometer at the maximum calibration temperature is so low that it affects the low-frequency response of the type of amplifier to be used, a low-frequency response calibration should be performed at that temperature. A number of frequencies shall be selected to describe adequately the frequency response. The calibration should be performed on the complete system, using the amplifier that is used with the accelerometer.

NOTE High temperature may affect the low-frequency response of the accelerometer as well as the noise and stability of the accelerometer-amplifier combination. Temperature response deviations are computed as the change in calibration factor determined at the test temperature referred to the room temperature (20 °C) calibration factor (measured at a frequency in the range of frequencies over which the transducer response is uniform). This change is expressed as a percentage of the room temperature calibration factor. It is usually desirable to select transducers which have temperature response deviations not exceeding +15 % throughout the temperature range of intended use.

4.3.2 Transient temperature sensitivity in piezo-electric transducers

Pyroelectric outputs are generated in all piezo-electric transducers subjected to transient temperatures. This is especially true for ferroelectric materials. The magnitude of the pyroelectric outputs depends upon the material constituting the crystal and the design of the transducer. Usually, the predominant frequency of the pyroelectric output is considerably less than 1 Hz. Also, most of the pyroelectric output from the transducer is filtered owing to the low-frequency characteristics of most amplifiers.

Accordingly, the pyroelectric output is dependent on the rate of change in temperature and on the characteristics of the amplifier, together with the characteristics of the transducer. The pyroelectric test is performed using the type of amplifier normally used with the transducer. The transducer is attached to an aluminium block by the usual means of attachment. Both are quickly immersed in an ice-water bath or a bath of other suitable liquid at a temperature which differs by approximately 20 °C from room temperature. The liquid in the bath should be described. The mass of the block should be approximately 10 times the mass of the transducer. Precautions are required to ensure that the liquid does not penetrate the transducer or that electrical leakage resistance is not lowered by the liquid at the connector, etc. The maximum amplifier output and the time from the start of the transient at which this maximum output is reached are measured on a direct-current oscilloscope or recorder. If the output reverses within the first 2 s and reaches a peak of opposite polarity, the magnitude and time of this peak are also recorded. For an accelerometer, the transient temperature sensitivity is expressed in equivalent metres per second squared per degree Celsius [(m/s^2)/°C] by dividing the maximum transducer output by the product of the difference between the bath temperature and room temperature and the accelerometer sensitivity.

For special applications using amplifiers having significantly different low-frequency characteristics, the pyroelectric test is performed with the specific amplifier to be used. Also, for applications in which the transient temperature rate differs greatly from that described by the above conditions, the test may be performed by simulating the particular temperature environment.

4.3.3 Transverse sensitivity ratio

The transverse sensitivity ratio (TSR) is usually determined at a single frequency below 500 Hz. The frequency used shall be reported. Sinusoidal motion is applied at a frequency at which it is known that the motion in a plane perpendicular to the sensing axis is at least 100 times the motion in the direction of the sensing axis. For transverse sensitivity ratios less than 1 %, the requirements for motion are more severe and extreme care and skill are required to obtain the value of the transverse sensitivity ratio.

The transducer is mounted and rotated about its sensing axis through 360°, in increments of 45° or less, to determine the maximum transverse response.

NOTE Experimental transverse sensitivity measurements on accelerometers indicate no detectable frequency dependence up to about 2 000 Hz. Only limited data are presently available regarding the transverse response within the frequency range from 2 000 Hz to 10 000 Hz. Several experimenters have stated that their measurement results usually indicate the high-frequency transverse response (that is, 2 000 Hz to 10 000 Hz) to be of the same order of magnitude as in a low-frequency determination (that is, less than 500 Hz). Generally, it is considered that for accelerometers whose axial resonance frequency is greater than 30 kHz, major transverse resonances will be greater than 10 kHz and, thus, beyond a transducer's normal operating range. For vibration transducers of other types, even less information is currently available. If possible, the lowest frequency of transverse resonance should be determined.

4.3.4 Sensitivity to rotational motion

Certain rectilinear vibration transducers are susceptible to rotational inputs. Examples of these include flexion-type piezo-electric and piezo-resistive accelerometers, and pendulum force-balance (servo) accelerometers. Attention is drawn to the existence of rotational sensitivity, and precautions may have to be taken to preclude a measurement error due to this effect. The rotational sensitivity of rectilinear vibration transducers can be determined by special methods developed for sensitivity calibrations of rotational vibration transducers (see reference [36]).

4.3.5 Strain sensitivity

The technique described below is the preferred method to determine the error produced in a transducer output due to bending of its base.

The transducer is mounted on a simple cantilever beam which produces a radius of curvature of 25 m and a strain of 250×10^{-6}.

A steel cantilever beam is clamped to a rigid support. The beam is 76 mm wide and 12,5 mm thick with a free length of 1 450 mm.

The natural frequency is very close to 5 Hz. The strain is measured by strain gauges bonded to the beam near the pickup mounting location about 40 mm from the clamped end. The motion at the mounting location can be checked by means of a transducer attached using extra isolation against base bending. A transducer with a calibration factor more than 10 times higher than the units under test is normally adequate. The outputs from the strain gauges and the transducer under test are recorded. The system is excited by manually deflecting the free end of the beam. The output of the transducer is recorded at a point where the strain in the surface of the beam is 250×10^{-6}. (This is equivalent to a radius of curvature of 25 m.) The error is the difference between the motion of the beam at the mounting location and the motion indicated by the transducer. The strain sensitivity, for a strain of 10^{-6}, is determined by dividing the above difference by 250.

The strain sensitivity should be tested at various strain amplitudes, in various directions. The maximum strain sensitivity of some transducers can produce significant errors in certain applications and mounting conditions. For example, some piezo-electric accelerometers produce error signals of several per cent at certain frequencies where strains are produced in vibration generators used for calibration purposes.

4.3.6 Magnetic sensitivity

The transducer is placed in a known magnetic field at 50 Hz or 60 Hz, and rotation of the transducer is started. The maximum electrical output of the transducer is recorded. For accelerometers, metres per second squared per tesla is recorded as the equivalent based on the sensitivity. For velocity transducers, metres per second per tesla over the useful frequency range is recorded as the equivalent. Induced mechanical vibrations and spurious electrical noise shall be eliminated from the test assembly.

4.3.7 Mounting torque sensitivity

The change in calibration factor due to transducer mounting torque is determined by applying torques of one-half the specified mounting torque, the specified, and twice the maximum specified. This test applies only to transducers that are mounted by screws, bolts, or other threaded fasteners. If more than one fastener is used in the normal mounting, the torques should be applied to each fastener.

Care should be taken to ensure that the transducer mounting surface is free from burrs or other surface defects which would prevent a flat mounting. The test surface to which the transducer is to be mounted should be flat and smooth and made from steel. The recommended values of flatness and roughness are a curvature less than 5 µm and an r.m.s. ground finish of 2 µm or better.

The test surface on which the transducer is to be mounted should be drilled and tapped square to the mounting surface with a perpendicularity of 0,05 mm or better (see ISO 1101). The interface lubrication normally recommended should be used and stated. The torque should always be applied from an unmounted condition, that is from zero torque for each of the three test torques. The torque sensitivity is recorded as the change in transducer calibration factor for one-half and twice the specified torque in relation to the specified torque. The uncertainty in the applied torque should not exceed ± 15 %.

4.3.8 Special environments

The operation of some transducers may be adversely affected in certain special environments, such as strong electrostatic, variable magnetic or radio-frequency fields, acoustic fields, in the case of cable effects, and nuclear irradiation. At present, there are no generally accepted techniques for measuring the effect of such special environments on a transducer, although special tests have been developed in instances where adverse effects could be expected (see ISO 2954).

5 Calibration methods

5.1 General

In order to perform a direct calibration of a transducer, it is necessary to use a vibration generator which applies a controllable and measurable input to the transducer and to provide a means for recording or measuring the output of the transducer. The transducer shall be attached to the vibration generator (or placed near it in the case of transducers whose output depends on the relative motion between the transducer and the vibrating object).

The attachment shall be sufficiently rigid to transmit the motion of the vibration generator to the transducer over the frequency range of the transducer. This requires that the natural frequency of the system, consisting of the transducer regarded as the mass and the attachment as the spring of a single-degree-of-freedom system, be high compared with the highest frequency component of the motion of the vibration generator. The vibration generator may be a support for tilting the transducer relative to the pull of gravity, a centrifuge, an electrodynamic vibration generator, or the anvil of a ballistic pendulum. The tilting support and centrifuge are used for calibration at zero frequency. Rotational calibration is used for low-frequency calibration for the Earth’s gravitational field. The electrodynamic vibration generator is normally used for steady-state sinusoidal calibrations. Ballistic pendulums, which apply transient excitation, may be used as a complementary method to the electrodynamic vibration generator, to bring out natural frequency response and to permit calibration a high accelerations and velocities. In addition, shock excitation may be used to verify transducer performance for high accelerations and velocity changes and to check that auxiliary instrumentation connected to the transducer functions properly under transient conditions.

A number of calibration methods are described in this part of ISO 16063 and they may be used for special purposes. However, the use of a laser interferometer is recommended for primary calibration. Whenever possible, it is recommended that standard transducers be calibrated by this method, and if only one frequency is used, this should preferably be 160 Hz, 80 Hz, 16 Hz or 8 Hz depending on the application. Frequency response may be obtained by calibration at discrete frequencies over the frequency range of interest or as the frequency response relative to the sensitivity at the reference frequency with less accuracy. Most other calibration needs can be covered by comparison against a standard transducer having primary calibration. The calibration is always referred to the moving base of the transducer and, for “back-to-back” calibration standards, to the mounting base for the unknown transducer.

5.2 Primary calibration methods

5.2.1 Calibration by measuring displacement amplitude and frequency

5.2.1.1 General

Many dynamic calibration methods depend on the accurate measurement of the displacement amplitude of the vibration to which the transducer is subjected. This method is generally used for continuous-reading transducers. The sinusoidal motion applied by the vibration generator should be along a well-defined straight line; lateral motions should be negligible.

The measured displacements can be used to calculate velocities, v, and accelerations, a, using the formulae $\hat{v} = 2\pi f \hat{s}$ and $\hat{a} = (2\pi f)^2 \hat{s}$ which are derived by single and double differentiation, respectively, for the sinusoidal displacement, s, and frequency, f. These formulae assume that the harmonic and noise content of the motion remains negligible even after the differentiation. They emphasize the need for minimizing the distortion due to the electrical power sources or due to other causes such as mechanical resonance. Harmonics are also objectionable since they may excite resonant response in a transducer.

Once the displacement amplitude is known, the transducer sensitivity may be calculated as the ratio of the measured transducer output to the velocity or the acceleration amplitude. The displacement shall be measured by laser interferometry. The method is well described in references [23] to [28], [37] and [38].

The methods of sensitivity calculation based on displacement amplitude measurement by laser interferometry generally give good accuracy from 0,1 Hz to 10 kHz (corresponding to displacement amplitudes of 0,5 m to 20 nm). Special methods based on interferometric displacement measurement allow primary phase calibration to be performed in addition to the sensitivity calibration. As an alternative to laser interferometry based on displacement measurement, good accuracy in absolute sensitivity and phase calibration of vibration transducers may also be achieved by current-state laser doppler velocimetry [39]. Considerable errors in the measurement of displacement will occur if the reference mirror is perturbed at the frequency (or a harmonically related frequency) at which the accelerometer is vibrated. Error may also result from perturbation of the beam splitter. It is advisable to monitor for such pertubation using a very sensitive accelerometer.

5.2.1.2 Theory for the ideal interferometer

The principle of operation is shown in Figure 1, where E_0, E_1 and E_2 represent the electric field vectors, and l_1 and l_2 represent the actual path lengths the beams have to travel after the beamsplitter. The displacement to be measured is represented by s (mirror 2).

The electric field vectors E_1 and E_2 can be represented by the formulae

$$E_1 = A_1 \exp\left[\mathrm{j}\left(\omega t + \frac{4\pi}{\lambda} l_1\right)\right]$$

$$E_2 = A_2 \exp\left\{\mathrm{j}\left[\omega t + \frac{4\pi}{\lambda}(l_2 + s)\right]\right\}$$

where λ is the wavelength of the laser light.