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Mechanical vibration and shock — Experimental determination of mechanical mobility —

Part 5:

Measurements using impact excitation with an exciter which is not attached to the structure

Vibrations et chocs mécaniques — Détermination expérimentale de la mobilité mécanique —

Partie 5: Mesurages à partir d'une excitation par choc appliquée par un excitateur non solidaire de la structure

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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 of the voluntary nature of standards, 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 www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*.

This second edition cancels and replaces the first edition (ISO 7626-5:1994), which has been technically revised.

The main changes compared with the previous edition are as follows:

- updating of normative and informative references in the bibliography;
- redrawing of figures and graphs.

A list of all parts in the ISO 7626 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

0.1 General introduction to the ISO 7626 series on mobility measurement

Dynamic characteristics of structures assumed to behave linearly can be determined as a function of frequency from mobility measurements or measurements of the related frequency-response functions (FRF), known as accelerance and dynamic compliance. Each of these frequency-response functions is the phasor of the motion response at a point on a structure due to a unit force (or moment) excitation at the same or any other point. The magnitude and the phase of these functions are frequency dependent.

Accelerance and dynamic compliance differ from mobility only in that the motion response is expressed in terms of acceleration or displacement, respectively, instead of velocity. In order to simplify the various parts of the ISO 7626 series, only the term “mobility” will be used. It is understood that all test procedures and requirements described are also applicable to the determination of accelerance and dynamic compliance.

Typical applications for mobility measurements are for:

a) predicting the dynamic response of structures to known or assumed input excitation;

b) determining the modal properties of a structure (natural frequencies, damping ratios and mode shapes);

c) predicting the dynamic interaction of interconnected structures;

d) checking the validity and improving the accuracy of mathematical models of structures;

e) determining the frequency dependent dynamic properties (i.e. the complex modulus of elasticity) of materials.

For some applications, a complete description of the dynamic characteristics can be required using measurements of forces and linear velocities along three mutually perpendicular axes as well as measurements of moments and rotational velocities about these three axes. This set of measurements results in a 6 × 6 mobility matrix for each location of interest. For N locations on a structure, the system thus has an overall mobility matrix of size $6N \times 6N$.

NOTE 1 In general, the measurement directions do not need to be perpendicular to each other, but only their linear independence is needed.

For most practical applications, it is not necessary to know the entire $6N \times 6N$ matrix. Often it is sufficient to measure the driving-point mobility and a few transfer mobilities by exciting with a force at a single point in a single direction and measuring the linear response motions at key points on the structure. In other applications, only rotational mobilities can be of interest.

In order to simplify its use in the various mobility measurement tasks encountered in practice, ISO 7626 is published as a series comprising:

- ISO 7626-1, which covers basic definitions and transducers. The information in ISO 7626-1 is common to most mobility measurement tasks.
- ISO 7626-2, which covers mobility measurements using single-point linear excitation with an attached exciter.
- ISO 7626-5 (this document), which covers mobility measurements using impact excitation with an exciter which is not attached to the structure.

Mechanical mobility is defined as the frequency-response function formed by the ratio of the phasor of the linear or rotational velocity response to the phasor of the applied force or moment excitation. If the response is measured with an accelerometer, conversion to velocity is used to obtain the mobility.

Alternatively, the ratio of acceleration to force, known as accelerance, can be used to characterize a structure. In other cases, dynamic compliance, the ratio of displacement to force, can be used.

NOTE 2 Historically, frequency-response functions of structures have often been expressed in terms of the reciprocal of one of the above-named dynamic characteristics. The arithmetic reciprocal of mechanical mobility has often been called mechanical impedance. However, this is misleading because the arithmetic reciprocal of mobility does not, in general, represent any of the elements of the impedance matrix of the structure. Mobility test data cannot be used directly as part of an analytic impedance model of the structure. To achieve compatibility of the data and the model, the impedance matrix of the model must be inverted to a mobility matrix, or vice versa. This point is elaborated upon in ISO 7626-1:2011, Annex A.

0.2 Introduction to this document

Impact excitation has become a popular method for measuring the frequency response of structures because of its inherent speed and relatively low cost to implement. However, the accuracy of mobility measurements made by using impact excitation is highly dependent upon both the characteristics of the test structure and the experimental techniques employed. With impact excitation, it can be difficult or impossible in certain cases to obtain the accuracy which is attainable using steady state or stationary excitation with an attached exciter, and the impact method carries an increased danger of gross measurement errors[6]. In spite of these limitations, impact testing can be an extremely useful excitation technique when applied properly.

This document provides a guide to the use of impact excitation for mobility measurements. Accurate mobility measurements always require careful attention to equipment selection and to the measurement techniques employed; these factors are especially important when using impact excitation. Furthermore, the characteristics of the test structure, especially its degree of nonlinearity, limit the accuracy which can be achieved. Subclause 4.2 describes these limitations on the use of impact excitation.

Because the exciter is not attached to the structure, this method makes it practical to measure a series of transfer mobilities of a structure by moving the excitation successively to each desired point on the structure, while the response motion transducer remains at a single fixed location and direction. Due to the principle of dynamic reciprocity, such measurements should be equal, assuming linearity, to the results obtained using an attached exciter at the same fixed location and direction with the response transducer relocated to each desired point on the structure. However, it can be difficult to impact the structure in all desired directions at certain locations, and in such cases, it can be more practical to use impact excitation at the fixed location and direction and relocate a multi-axis response transducer to the desired response locations.

NOTE 1 When a multi-axis transducer is used at a fixed location for a modal test and if the impact is applied in one direction of the transducer at each point, then only the mode shape components in that direction are obtained.

NOTE 2 The mass of the multiaxial transducer can change the mass properties of the structure leading to an inconsistent set of measured transfer functions. This can cause serious problems in using the FRFs for experimental modal analysis.

Mechanical vibration and shock — Experimental determination of mechanical mobility —

Part 5:
Measurements using impact excitation with an exciter which is not attached to the structure

1 Scope

This document specifies procedures for measuring mechanical mobility and other frequency-response functions of structures excited by means of an impulsive force generated by an exciter which is not attached to the structure under test.

It is applicable to the measurement of mobility, accelerance or dynamic compliance, either as a driving point measurement or as a transfer measurement, using impact excitation. Other excitation methods, such as step relaxation and transient random, lead to signal-processing requirements similar to those of impact data. However, such methods are outside the scope of this document because they involve the use of an exciter which is attached to the structure.

The signal analysis methods covered are all based on the discrete Fourier transform (DFT), which is performed mostly by a fast Fourier transform (FFT) algorithm. This restriction in scope is based solely on the wide availability of equipment which implements these methods and on the large base of experience in using these methods. It is not intended to exclude the use of other methods currently under development.

Impact excitation is also widely used to obtain uncalibrated frequency-response information. For example, a quick impact test which obtains approximate natural frequencies and mode shapes can be quite helpful in planning a random or sinusoidal test for accurate mobility measurements. These uses of impact excitation to obtain qualitative results can be a first stage for mobility measurements.

This document is limited to the use of impact excitation techniques for making accurate mobility measurements.

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 2041, *Mechanical vibration, shock and condition monitoring — Vocabulary*

3 Terms and definitions

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

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

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
frequency-response function
FRF
frequency-dependent ratio of Fourier transform of the motion-response of a linear system to the one of the excitation force

Note 1 to entry: Frequency-response functions are properties of linear dynamic systems which do not depend on the type of excitation function. Excitation may be harmonic, random or transient functions of time. The test results obtained with one type of excitation may thus be used for predicting the response of the linear system to any other type of excitation.

Note 2 to entry: Linearity of the system is a condition which, in practice, may be met only approximately, depending on the type of system and on the magnitude of the input. Care has to be taken to avoid nonlinear effects, particularly when applying impulse excitation. Structures which are known to be nonlinear (for example, certain riveted structures) should not be tested with impulse excitation and great care is required when using random excitation for testing such structures.

Note 3 to entry: Motion may be expressed in terms of either displacement, velocity or acceleration; the corresponding frequency-response function designations are dynamic compliance, mobility and accelerance or dynamic stiffness, impedance, and effective mass, respectively.

Note 4 to entry: In practice, the discrete Fourier transform (DFT) by the fast Fourier transform (FFT) is used as an approximation of the continuous Fourier transform. The errors of this approximation can be reduced to levels below those of other measurement errors. Hence, the use of the DFT does not necessarily limit the accuracy of the measurement.

3.2
frequency range of interest
span, in hertz, from the lowest frequency to the highest frequency at which mobility data are to be obtained in a given test series

3.3
power spectral density
square of absolute value of the FFT of a signal multiplied by 2/T where T is the length of the time signal, meaning mean-square value of a time signal per unit bandwidth

3.4
energy spectral density
power spectral density (3.3) multiplied by the length of the record in seconds, which is used in the spectral calculation of a transient signal

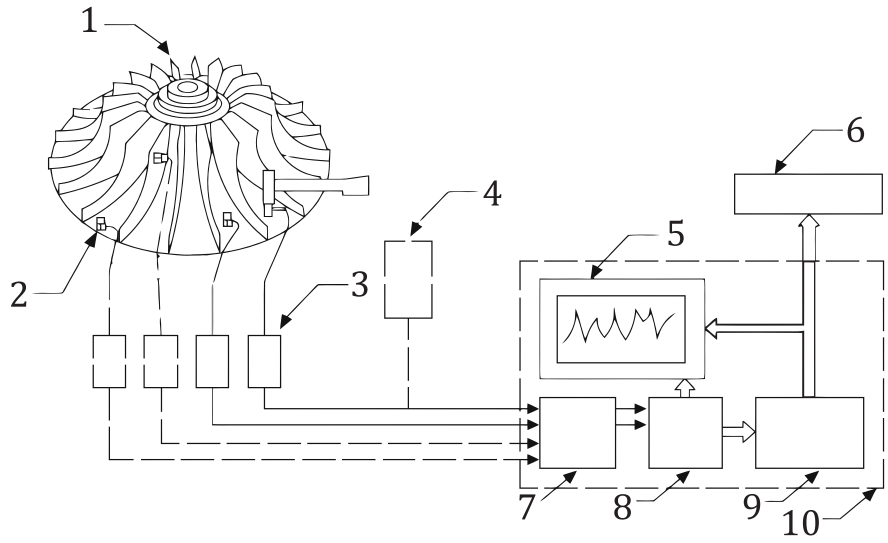
Note 1 to entry: This definition assumes that the transient signal is entirely contained within the record.

4 General characteristics of impact measurements

4.1 General description

The instrumentation required for mobility measurements using impact excitation consists of an impact hammer with built-in force transducer, one or more motion-response transducers with their associated signal conditioners and a digital Fourier transform analysis system or analyser having at least two simultaneous input channels. The instrumentation system is shown schematically in Figure 1. This document provides information on the selection and use of these components.

The force and response signals from each impact are anti-aliasing filtered and then digitally sampled using the pre-triggering or transient capture mode of the analyser. Each of the resulting digital records should represent a single impact event. The discrete Fourier transform of each record is computed by the analyser. Frequency domain averaging of several frequency-response functions obtained from impacts at a given point may be performed to improve the estimate.



Key

1	structure under test
2	motion-response transducer(s)
3	signal conditioners
4	storage oscilloscope
5	display
6	output device (printer/plotter)
7	amplifiers and analogue anti-aliasing filter
8	analogue/digital converter
9	DFT/FFT and FRF computation
10	signal analyser

______	basic feature
--------	optional feature
DFT	discrete Fourier transform
FFT	fast Fourier transform
FRF	frequency response function

Figure 1 — Instrumentation block diagram for impact excitation

4.2 Advantages and limitations of impact excitation

4.2.1 General

Impact excitation offers the following intrinsic advantages compared with the use of an attached exciter:

a) measurement speed;

b) ease of installation;

c) ease of relocating the excitation point;

d) no change of structure, which can be caused by the exciter attachment method (see ISO 7626-2).

On the other hand, the following limitations of impact excitation shall be taken into account:

a) nonlinearity restrictions;

b) signal-to-noise problems;

c) limited frequency resolution;

d) damping restrictions;

e) dependence on operator skill.

These limitations are discussed in 4.2.2 to 4.2.6.

4.2.2 Nonlinearity restrictions

Mobility measurements on structures which exhibit a significant degree of nonlinearity always demand special precautions. In such cases, the use of sinusoidal or random excitation with an attached exciter is preferred, if practical, instead of the impact-excitation technique.

With the impact-excitation technique, the energy needed to drive the response signal to a certain magnitude is put into the structure during a limited part of the time period used for analysis. Compared with sinusoidal or random excitation, the force of the impact pulse therefore can be much larger and the effects of nonlinearity are thus likely to be increased.

For measurements on systems with a significant degree of nonlinearity, it is very important to keep a level of the force used for the excitation or a level of the system response. In this aspect, the sinusoidal excitation techniques are preferable. If a hand-held hammer is used to generate the impacts, the individual force amplitudes can vary significantly. The repeatability of such a measurement can be poor for nonlinear systems.

4.2.3 Signal-to-noise problems

Because the average signal levels are low compared with the peak levels, impact measurements require a very low noise testing environment and the maximum possible dynamic range in the measurement system. This requirement can rule out the use of current analogue tape-recording techniques.

A significant noise problem can occur because the force signal duration is short compared with the total record length. This situation can result in the instrumentation electrical noise and the mechanically induced background noise having a mean square value that is significant compared with the mean square value of the input force. Such noise can be reduced by the windowing techniques described in 8.5.

4.2.4 Limited frequency resolution

The frequency increment, in hertz, which results from a discrete Fourier transform (including the case of a band-limited or “zoom” analysis), is equal to the reciprocal of the record length, in seconds. Because each record represents a single impact event, the record length is effectively limited to the time required for the impulse response of the structure to decay to the level of the background noise. Therefore, the frequency resolution attainable depends on both the response of the structure and the background noise level. In some cases, it can be impractical (and unnecessary) using impact excitation to achieve directly the frequency resolution specified in ISO 7626-2; however, accurate mobility values can be obtained at discrete frequencies with sufficiently fine resolution for most applications. If the test structure exhibits high modal density (i.e. multiple resonances within a narrow frequency band), it can be difficult to achieve sufficiently fine resolution for an accurate mobility measurement. In those cases, one of the steady-state excitation methods with “zoom” analysis is preferred.

By its very nature, the spectrum of an impact extends from DC to some upper frequency limit (see Clause 6). This inability to band limit the excitation spectrum restricts the usefulness of “zoom” analysis for improving the frequency resolution of impact measurements, and the impact places further demands on the dynamic range of the measurement system. It also increases the danger of undetected overloads (clipping) in the measurement system due to high-amplitude out-of-band signals. See 6.3 and 8.4. The time resolution has to be high enough for the impact signal to be recorded at a sufficient number of sampling points. However, a higher time resolution can decrease the frequency resolution when the number of data points for the FFT is fixed.

4.2.5 Damping restrictions

Impact excitation has limitations for testing heavily damped structures because the short duration of the response signal leads to a trade-off between frequency resolution and background noise level, as discussed in 4.2.4. This limitation can also be understood as a manifestation of the inherently low average energy level for a given impact force magnitude. Heavily damped structures can require higher energy excitation in order to balance their high internal energy dissipation characteristics and to produce sufficient response data for accurate measurement.

A different problem occurs if the structure has extremely light damping. The frequency-response functions of such a structure exhibit very sharp resonance peaks which requires high-resolution zoom measurements for accurate definition, as discussed in 4.2.4. The use of an exponential decay window can help by adding a known amount of artificial decay to the data. If windowing is used, the resulting mobility data or modal damping values therefrom have to be corrected, as described in 8.5 and Annex A.

4.2.6 Dependence on operator skill

The accuracy of mobility measurements performed using a hand-held impact hammer depends on the ability of the operator to maintain the correct location and direction of impact. These effects can normally be held within acceptable limits if the impacts are applied carefully, but they can be significant if the test structure is small and requires very fine spatial resolution.

Operator skill is also required in order to avoid a double hit of impactor; see 6.4. If there are high demands on the quality, the shock may be applied by a mechanical pendulum to avoid double hits.

5 Support of the structure under test

5.1 General

Mobility measurements may be performed on structures either in an ungrounded condition (freely suspended) or in a grounded condition (attached to one or more supports), depending on the objective of the test.

5.2 Ungrounded measurements

Ungrounded measurements employ a compliant suspension of the test structure. The magnitudes of the driving-point mobility of the suspension at points of attachments should be at least ten times greater than the magnitudes of the mobility of the structure at the same attachment points.

5.3 Grounded measurements

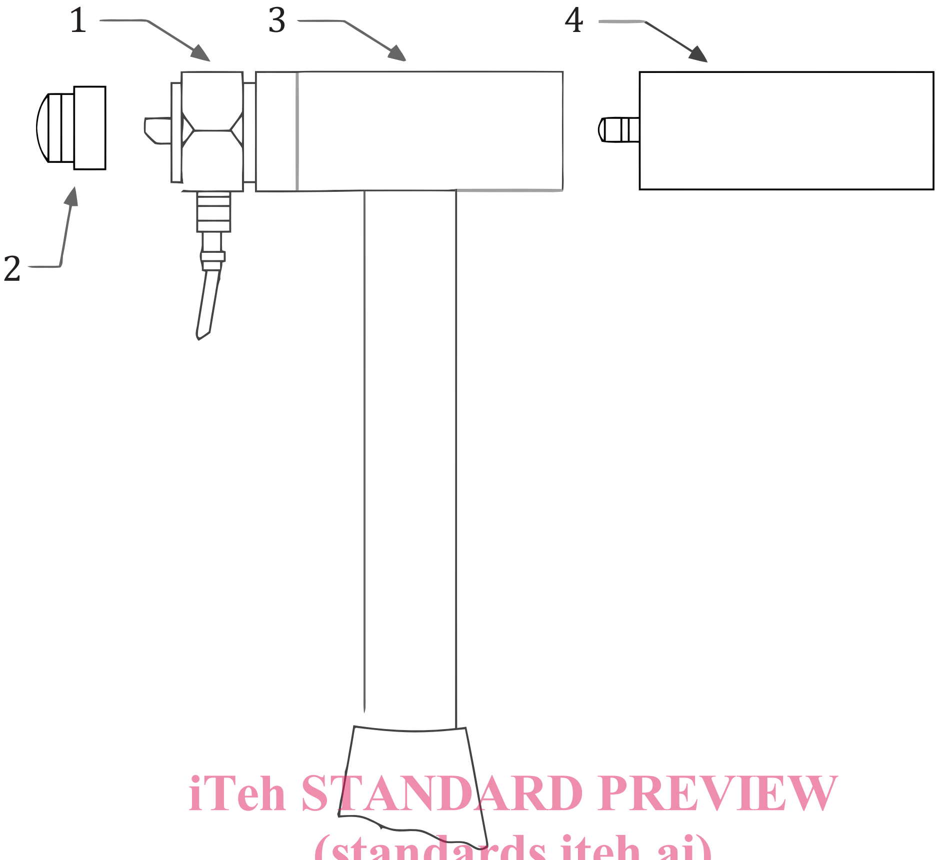
Grounded measurements employ a support of the test structure which is representative of its support in typical applications, unless otherwise specified. A description of the support and attachment should be included in the test report.

FRFs and modal parameters resulting from grounded measurements can differ significantly from those measured in ungrounded (free-free) configuration. Due to the clamping, the structure is stiffened in general and, hence, the natural frequencies increase.

6 Application of the excitation

6.1 Impactor design

A typical impactor consists of a rigid mass with a force transducer attached to one end and an impact tip attached to the opposite side of the force transducer, as shown schematically in Figure 2. The tip stiffness and impactor mass shall be selected as described in 6.3, in order to achieve a force pulse of the desired duration and to avoid double hits.



Key

1	force transducer
2	interchangeable impactor tip
3	mass
4	interchangeable mass

Figure 2 — Typical impactor

For small values of impactor mass, the impactor often takes the form of a hand-held hammer with interchangeable tips and masses. However, the accuracy obtained using a hand-held impactor depends on the skill of the operator in maintaining the correct location and direction of impact. For small test structures, it is necessary to provide a suitable mechanical device to guide the impactor to a repeatable location and direction on the structure. For testing large structures which require higher energy, the impactor may take the form of a large mass suspended from cables and either dropped or swung. Alternatively, a smaller mass may be accelerated to a high impact velocity by a spring, solenoid pneumatic actuator or other means.

The area of the impact surface of the tip should be large enough to withstand the maximum force employed without permanent deformation of either the tip or the test structure. On the other hand, a small tip area is necessary if very fine spatial resolution of the location is required. The velocity vector of the impactor at the moment of impact should be in line with the sensing axis of the force transducer and should be perpendicular to the surface of the test structure at the point of impact within 10°. It is generally easier to maintain the proper orientation if the impactor body is relatively long compared with its cross-sectional dimensions.

6.2 Force spectrum characteristics

A theoretical (Dirac) impulse of infinitesimal duration contains equal energy at all frequencies. However, the spectrum of any actual force pulse has a finite usable bandwidth which is inversely proportional to