INTERNATIONAL STANDARD

ISO 10846-1

Second edition
2008-08-15

Acoustics and vibration — Laboratory measurement of vibro-acoustic transfer properties of resilient elements —

Part 1: Principles and guidelines

Acoustique et vibrations — Mesurage en laboratoire des propriétés de transfert vibro-acoustique des éléments élastiques —

Partie 1: Principes et lignes directrices

Reference number
ISO 10846-1:2008(E)

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Published in Switzerland

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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 10846-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*, and ISO/TC 108, *Mechanical vibration, shock and condition monitoring*.

This second edition cancels and replaces the first edition (ISO 10846-1:1997), which has been technically revised.

ISO 10846 consists of the following parts, under the general title *Acoustics and vibration — Laboratory measurement of vibro-acoustic transfer properties of resilient elements*:

— *Part 1: Principles and guidelines*

— *Part 2: Direct method for determination of the dynamic stiffness of resilient supports for translatory motion*

— *Part 3: Indirect method for determination of the dynamic stiffness of resilient supports for translatory motion*

— *Part 4: Dynamic stiffness of elements other than resilient supports for translatory motion*

— *Part 5: Driving point method for determination of the low-frequency transfer stiffness of resilient supports for translatory motion*

Introduction

Passive vibration isolators of various kinds are used to reduce the transmission of vibrations. Examples include automobile engine mounts, resilient supports for buildings, resilient mounts and flexible shaft couplings for shipboard machinery and small isolators in household appliances.

This part of ISO 10846 serves as an introduction and a guide to ISO 10846-2, ISO 10846-3, ISO 10846-4 and ISO 10846-5, which describe laboratory measurement methods for the determination of the most important quantities which govern the transmission of vibrations through linear resilient elements, i.e. frequency-dependent dynamic transfer stiffnesses. This part of ISO 10846 provides the theoretical background, the principles of the methods, the limitations of the methods, and guidance for the selection of the most appropriate standard of the series.

The laboratory conditions described in all parts of ISO 10846 include the application of static preload, where appropriate.

The results of the methods are useful for resilient elements, which are used to prevent low-frequency vibration problems and to attenuate structure-borne sound. However, for complete characterization of resilient elements that are used to attenuate low-frequency vibration or shock excursions, additional information is needed, which is not provided by these methods.

Acoustics and vibration — Laboratory measurement of vibro-acoustic transfer properties of resilient elements —

Part 1: Principles and guidelines

1 Scope

This part of ISO 10846 explains the principles underlying ISO 10846-2, ISO 10846-3, ISO 10846-4 and ISO 10846-5 for determining the transfer properties of resilient elements from laboratory measurements, and provides assistance in the selection of the appropriate part of this series. It is applicable to resilient elements that are used to reduce

a) the transmission of audio frequency vibrations (structure-borne sound, 20 Hz to 20 kHz) to a structure which may, for example, radiate fluid-borne sound (airborne, waterborne, or other), and

b) the transmission of low-frequency vibrations (typically 1 Hz to 80 Hz), which may, for example, act upon human subjects or cause damage to structures of any size when the vibration is too severe.

The data obtained with the measurement methods, which are outlined in this part of ISO 10846 and further detailed in ISO 10846-2, ISO 10846-3, ISO 10846-4 and ISO 10846-5, can be used for

— product information provided by manufacturers and suppliers,

— information during product development,

— quality control, and

— calculation of the transfer of vibrations through resilient elements.

The conditions for the validity of the measurement methods are

a) linearity of the vibrational behaviour of the resilient elements (this includes elastic elements with non-linear static load-deflection characteristics, as long as the elements show approximate linearity for vibrational behaviour for a given static preload), and

b) the contact interfaces of the vibration isolator with the adjacent source and receiver structures can be considered as point contacts.

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 2041:—[1], *Mechanical vibration, shock and condition monitoring — Vocabulary*

1) To be published. (Revision of ISO 2041:1990)

ISO/IEC Guide 98-3 2), *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM 1995)*

3 Terms and definitions

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

3.1
vibration isolator
resilient element
isolator designed to attenuate the transmission of the vibration in a certain frequency range

NOTE Adapted from ISO 2041:—1), definition 2.120.

3.2
resilient support
vibration isolator(s) suitable for supporting a machine, a building or another type of structure

3.3
test element
resilient element undergoing testing, including flanges and auxiliary fixtures, if any

3.4
blocking force
F_b
dynamic force on the output side of a vibration isolator which results in a zero displacement output

3.5
dynamic driving point stiffness
$k_{1,1}$
frequency-dependent ratio of the force phasor $\underline{F}_1$ on the input side of a vibration isolator with the output side blocked to the displacement phasor $\underline{u}_1$ on the input side

$$k_{1,1} = \underline{F}_1 / \underline{u}_1$$

NOTE 1 The subscripts "1" denote that the force and displacement are measured on the input side.

NOTE 2 The value of $k_{1,1}$ can be dependent on the static preload, temperature, relative humidity and other conditions.

NOTE 3 At low frequencies, elastic and dissipative forces solely determine $k_{1,1}$. At higher frequencies, inertial forces play a role as well.

3.6
dynamic driving point stiffness of inverted vibration isolator
$k_{2,2}$
dynamic driving point stiffness, with the physical input and output sides of the vibration isolator interchanged

NOTE At low frequencies, where elastic and dissipative forces solely determine the driving point stiffness, $k_{1,1} = k_{2,2}$. At higher frequencies inertial forces play a role as well and $k_{1,1}$ and $k_{2,2}$ will be different in case of asymmetry.

2) ISO/IEC Guide 98-3 will be published as a re-issue of the *Guide to the expression of uncertainty in measurement* (GUM), 1995.

3.7
dynamic transfer stiffness
$k_{2,1}$
frequency-dependent ratio of the blocking force phasor $\underline{F}_{2,\mathrm{b}}$ on the output side of a resilient element to the displacement phasor $\underline{u}_1$ on the input side

$$k_{2,1} = \underline{F}_{2,\mathrm{b}} / \underline{u}_1$$

NOTE 1 The subscripts "1"and "2" denote the input and output sides, respectively.

NOTE 2 The value of $k_{2,1}$ can be dependent on the static preload, temperature and other conditions.

NOTE 3 At low frequencies, $k_{2,1}$ is mainly determined by elastic and dissipative forces and $k_{1,1} \approx k_{2,1}$. At higher frequencies, inertial forces in the resilient element play a role as well and $k_{1,1} \neq k_{2,1}$.

3.8
loss factor of resilient element
η
ratio of the imaginary part of $k_{2,1}$ to the real part of $k_{2,1}$, i.e. tangent of the phase angle of $k_{2,1}$, in the low-frequency range where inertial forces in the element are negligible

3.9
point contact
contact area which vibrates as the surface of a rigid body

3.10
linearity
property of the dynamic behaviour of a resilient element, if it satisfies the principle of superposition

NOTE 1 The principle of superposition can be stated as follows: if an input $x_1(t)$ produces an output $y_1(t)$ and in a separate test an input $x_2(t)$ produces an output $y_2(t)$, superposition holds if the input $a\,x_1(t) + b\,x_2(t)$ produces the output $a y_1(t) + b\,y_2(t)$. This must hold for all values of a, b and $x_1(t)$, $x_2(t)$; a and b are arbitrary constants.

NOTE 2 In practice, the above test for linearity is impractical and a limited check of linearity is performed by measuring the dynamic transfer stiffness for a range of input levels. For a specific preload, if the dynamic transfer stiffness is nominally invariant, the system can be considered linear. In effect, this procedure checks for a proportional relationship between the response and the excitation.

3.11
direct method
method in which either the input displacement, velocity or acceleration and the blocking output force are measured

3.12
indirect method
method in which the vibration transmissibility (for displacement, velocity or acceleration) of a resilient element is measured, with the output loaded by a compact body of known mass

NOTE The term "indirect method" can be permitted to include loads of any known impedance other than a mass-like impedance. However, the ISO 10846 series does not cover such methods.

3.13
driving point method
method in which either the input displacement, velocity or acceleration and the input force are measured, with the output side of the resilient element blocked

3.14
flanking transmission
forces and accelerations at the output side caused by the vibration exciter on the input side but via transmission paths other than through the resilient element under test

3.15
upper limiting frequency
f_{UL}
frequency up to which results for $k_{1,2}$ are valid, according to the criteria given in various parts of ISO 10846

4 Selection of appropriate International Standard

Table 1 provides guidance for the selection of the appropriate part of ISO 10846.

Table 1 — Guidance for selection

	International Standard and method type			
	ISO 10846-2 **Direct method**	**ISO 10846-3** **Indirect method**	**ISO 10846-4** **Direct or indirect method**	**ISO 10846-5** **Driving point method**
Type of resilient element	support	support	other than support	support
Examples	resilient mountings for instruments, equipment, machinery and buildings		bellows, hoses, resilient shaft couplings, power supply cables	see under ISO 10846-2 and ISO 10846-3
Frequency range of validity	1 Hz to f_{UL} f_{UL} dependent on test rig; typically (but not limited to) 300 Hz $< f_{UL} <$ 500 Hz	f_2 to f_3 f_2 typically (but not limited to) between 20 Hz and 50 Hz. For very stiff mountings $f_2 >$ 100 Hz. f_3 typically 2 kHz to 5 kHz, but dependent on the test rig	Direct method: see under ISO 10846-2; Indirect method: see under ISO 10846-3	1 Hz to f_{UL} f_{UL} typically (but not limited to) $<$ 200 Hz f_{UL} is dependent both on test rig and on test element properties;
Translational components	1, 2 or 3	1, 2 or 3	1, 2 or 3	1, 2 or 3
Rotational components	none	informative annex	informative annex	none
Expanded measurement uncertainty for 95 % coverage probability	To be estimated according to ISO/IEC Guide 98-3	4 dB (considered as the upper limit)	4 dB (considered as the upper limit)	To be estimated according to ISO/IEC Guide 98-3

NOTE Within coinciding frequency ranges of validity, and within the uncertainty ranges of the methods, the direct method, the indirect method and the driving point method yield the same result.

Further guidance is given in Clauses 5 and 6.

5 Theoretical background

5.1 Dynamic transfer stiffness

This clause explains why the dynamic transfer stiffness is most appropriate to characterize the vibro-acoustic transfer properties of resilient elements for many practical applications. It also describes special situations where other vibro-acoustic properties, not covered in ISO 10846, would also be necessary.

The dynamic transfer stiffness, as defined in 3.7, is determined by the elastic, inertia and damping properties of the resilient element. Describing the test results in terms of stiffness properties allows for compliance with data of static and/or low-frequency dynamic stiffness, which are commonly used. The additional importance of inertial forces (i.e. elastic wave effects in the isolators) makes the dynamic transfer stiffness at high frequencies more complex than at low frequencies. At low frequencies, only elastic and damping forces are important. Because in general the modulus of elasticity and the damping properties are only weakly dependent on frequency in this range, this holds also for the low-frequency dynamic stiffness.

NOTE For many resilient elements, static stiffness and low-frequency dynamic transfer stiffness are different.

In principle, the dynamic transfer stiffness of vibro-acoustic resilient elements is dependent on static preload, temperature and relative humidity. In the following theory, linearity, as defined in 3.10, is assumed. See Annex D for further information.

Relationships between the dynamic transfer stiffness and other quantities are listed in Annex A. These relationships imply that, for the actual performance of the tests, only practical considerations will determine whether displacements, velocities or accelerations are measured. However, for presentation of the results in agreement with the other parts of ISO 10846, appropriate conversions may be needed.

5.2 Dynamic stiffness matrix of resilient elements

5.2.1 General concept

A familiar approach to the analysis of complex vibratory systems is the use of stiffness – compliance – or transmission matrix concepts. The matrix elements are basically special forms of frequency-response functions; they describe linear properties of mechanical and acoustical systems. On the basis of the knowledge of the individual subsystem properties, corresponding properties of assemblies of subsystems can be calculated. The three matrix forms mentioned above are interrelated and can be readily transformed amongst themselves [5]. However, only stiffness-type quantities are specified in ISO 10846 for the experimental characterization of resilient elements under static preload.

The general conceptual framework for the specified characterization of resilient elements is shown in Figure 1.

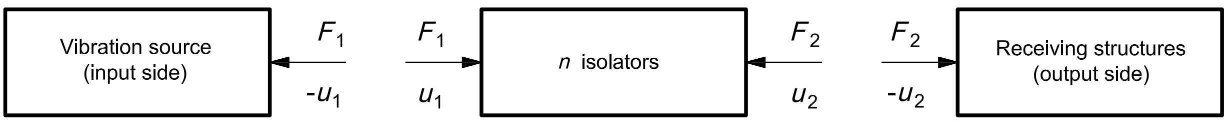

Figure 1 — Block diagram of source/isolators/receiver system

The system consists of three blocks, which respectively represent the vibration source, a number n of isolators and the receiving structures. A point contact is assumed at each connection between source and isolator and between isolator and receiver. To each connection point, a force vector $\boldsymbol{F}$ containing three orthogonal forces and three orthogonal moments and a displacement vector[3)] $\boldsymbol{u}$ containing three orthogonal translational components and three orthogonal rotational components are assigned. In Figure 1, just one component of each of the vectors $\boldsymbol{F}_1$, $\boldsymbol{u}_1$, $\boldsymbol{F}_2$ and $\boldsymbol{u}_2$ is shown. These vectors contain $6n$ elements, where n denotes the number of isolators.

To show that the blocked transfer stiffness, defined in 3.7 as dynamic transfer stiffness, is suitable for isolator characterization in many practical cases, the discussion will proceed from the simplest case of unidirectional vibration to the multidirectional case for a single isolator.

3) Linear algebra: a vector is a linear array of elements.

5.2.2 Single isolator, single vibration direction

For unidirectional vibration of a single vibration isolator, the isolator equilibrium may be expressed by the following stiffness equations:

$$\underline{F}_1 = k_{1,1}\,\underline{u}_1 + k_{1,2}\,\underline{u}_2 \tag{1}$$

$$\underline{F}_2 = k_{2,1}\,\underline{u}_1 + k_{2,2}\,\underline{u}_2 \tag{2}$$

where

$k_{1,1}$ and $k_{2,2}$ are driving point stiffnesses when the isolator is blocked at the opposite side (i.e. $\underline{u}_2 = 0$, $\underline{u}_1 = 0$, respectively);

$k_{1,2}$ and $k_{2,1}$ are blocked transfer stiffnesses, i.e. they denote the ratio between the force on the blocked side and the displacement on the driven side. $k_{1,2} = k_{2,1}$ for passive isolators, because passive linear isolators are reciprocal.

Due to increasing inertial forces, $k_{1,1}$ and $k_{2,2}$ become different at higher frequencies. At low frequencies, only elastic and damping forces play a role, making all $k_{i,j}$ equal.

NOTE 1 These equations are for single frequencies. $\underline{F}_i$ and $\underline{u}_i$ are phasors and $k_{i,j}$ are complex quantities.

The matrix form of Equations (1) and (2) is

$$\boldsymbol{F} = \boldsymbol{K}\boldsymbol{u} \tag{3}$$

with the dynamic stiffness matrix

$$\boldsymbol{K} = \begin{bmatrix} k_{1,1} & k_{1,2} \\ k_{2,1} & k_{2,2} \end{bmatrix} \tag{4}$$

For excitation of the receiving structure via the isolator

$$k_t = -\frac{\underline{F}_2}{\underline{u}_2} \tag{5}$$

where k_t denotes the dynamic driving point stiffness of the termination. The minus sign is a consequence of the convention adopted in Figure 1.

From Equations (2) and (5) it follows that

$$\underline{F}_2 = \frac{k_{2,1}}{1 + \dfrac{k_{2,2}}{k_t}}\,\underline{u}_1 \tag{6}$$

Therefore, for a given source displacement $\underline{u}_1$, the force $\underline{F}_2$ depends both on the isolator driving point dynamic stiffness and on the receiver driving point dynamic stiffness. However, if $|k_{2,2}| < 0{,}1|k_t|$, then $\underline{F}_2$ approximates the so-called blocking force to within 10 %, i.e.

$$\underline{F}_2 \approx \underline{F}_{2,b} = k_{2,1}\underline{u}_1 \tag{7}$$

Because vibration isolators are only effective between structures of relatively large dynamic stiffness on both sides of the isolator, Equation (7) represents the intended situation at the receiver side. This forms the background for the measurement methods of ISO 10846. Measurement of the blocked transfer stiffness (or a directly related function) for an isolator under static preload is easier than measurement of the complete

