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

**Part 1:  
Principles and guidelines**

iTeh STANDARD PREVIEW

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

*Partie 1: Principes et lignes directrices*

ISO 10846-1:1997

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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.

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

Annexes A to E of this part of ISO 10846 are for information only.

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International Organization for Standardization  
Case postale 56 • CH-1211 Genève 20 • Switzerland  
Internet central@iso.ch  
X.400 c=ch; a=400net; p=iso; o=isocs; s=central

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## Introduction

Passive vibration isolators of various kinds are used to reduce the transmission of vibrations. Examples are automobile engine mounts, elastic supports for buildings, elastic 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 parts 2 to 5 of ISO 10846, which describe laboratory measurement methods for the determination of the most important quantities which govern the transmission of vibrations through linear isolators, i.e. frequency-dependent dynamic 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.

The results of the methods are useful for isolators which are used to prevent low-frequency vibration problems and to attenuate structure-borne sound. The methods are not sufficiently appropriate to characterize completely isolators which are used to attenuate shock excursions.

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# 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 parts 2 to 5 of ISO 10846 for determining the transfer properties of vibration isolators from laboratory measurements, and provides assistance in the selection of the appropriate part of this series.

This part of ISO 10846 is applicable to vibration isolators which are used to reduce:

- a) the transmission of audiofrequency vibrations (structure-borne sound, 20 Hz to 20 kHz) to a structure which may, for example, radiate fluid-borne sound (airborne, waterborne, or other);
- b) the transmission of low frequency vibrations (typically 1 Hz to 80 Hz) which may, for example, act upon humans or cause damage to structures when vibration is too severe.

The data obtained with the measurement methods which are outlined in this part of ISO 10846 and further detailed in parts 2 to 5 of ISO 10846 can be used for:

- product information provided by manufacturers and suppliers;  
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- information during product development;
- quality control;
- computation of the transfer of vibrations through isolators.

The conditions for the validity of the measurement methods are

- a) linearity of the vibrational behaviour of the isolator (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);
- b) the contact interfaces of the vibration isolator with the adjacent source and receiver structures can be considered as point contacts.

### 2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this part of ISO 10846. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this part of ISO 10846 are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of ISO and IEC maintain registers of currently valid International Standards.

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

### 3 Definitions

For purposes of this part of ISO 10846, the definitions given in ISO 2041 and the following apply.

#### 3.1 resilient element

(see vibration isolator)

#### 3.2 vibration isolator

isolator designed to attenuate the transmission of vibration in a frequency range [ISO 2041:1990, 2.110]

#### 3.3 elastic support

vibration isolator suitable for supporting a part of the mass of a machine, a building or another type of structure

#### 3.4 blocking force

$F_b$   
dynamic force at the output side of a vibration isolator which results in zero displacement output

#### 3.5 dynamic driving point stiffness

$k_{1,1}$   
frequency-dependent complex ratio of the force on the input side of a vibration isolator with the output side blocked to the complex displacement on the input side during simple harmonic vibration

NOTE 1  $k_{1,1}$  may depend on the static preload, temperature and other conditions.

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

#### 3.6 dynamic transfer stiffness

$k_{2,1}$   
frequency-dependent complex ratio of the force on the blocked output side of a vibration isolator to the complex displacement on the input side during simple harmonic vibration

NOTE 1  $k_{2,1}$  may depend on the static preload, temperature and other conditions.

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

#### 3.7 loss factor of resilient element

$\eta$   
frequency-dependent 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

#### 3.8 point contact

contact area which vibrates as the surface of a rigid body

#### 3.9 linearity

property of the dynamic behaviour of a vibration isolator 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  $\alpha x_1(t) + \beta x_2(t)$  produces the output  $\alpha y_1(t) + \beta y_2(t)$ . This must hold for all values of  $\alpha$ ,  $\beta$  and  $x_1(t)$ ,  $x_2(t)$ ;  $\alpha$  and  $\beta$  are arbitrary constants.

NOTE 2 In practice the above test for linearity is impractical and a limited check of linearity is done 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.

### 3.10

#### direct method

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

### 3.11

#### indirect method

method in which the transmissibility (for displacement, velocity or acceleration) of an isolator is measured, with the output loaded by a mass/effective mass

### 3.12

#### 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 vibration isolator blocked

## 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 Indirect method	ISO 10846-5 Driving point method
Type of vibration isolator	support	support	other than support	support
Examples	resilient mountings for instruments, equipment, machinery and buildings		bellows, hoses, elastic shaft couplings, power supply cables	see under ISO 10846-2 and ISO 10846-3
Frequency range	1 Hz to $f_1$ $f_1$ dependent on test rig; typically (but not limited to) 300 Hz < $f_1$ < 500 Hz	$f_2$ to $f_3$ $f_2$ typically (but not limited to) 20 Hz to 50 Hz. For very stiff mountings $f_2$ > 100 Hz. $f_3$ typically 2 kHz to 5 kHz, but dependent on the test rig	$f_2$ to $f_3$ $f_2$ typically (but not limited to) 20 Hz to 50 Hz. For very stiff elements $f_2$ > 100 Hz. $f_3$ typically 2 kHz to 5 kHz, but dependent on the test rig	1 Hz to $f_4$ $f_4$ typically (but not limited to) < 100 Hz
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
Classification of method	engineering	engineering	engineering/survey	engineering/survey
NOTE At the low-frequency end, the direct 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 isolators for many practical applications. It also indicates briefly for which special situations other vibro-acoustic isolator properties, of which the measurement is not covered in ISO 10846, would be needed in addition.

The dynamic transfer stiffness, as defined in 3.6, is determined by the elastic, inertia and damping properties of the isolator. The reason for choosing a presentation of test results in terms of a stiffness is the practical consideration that it complies 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. Because at low frequencies only elastic and damping forces are important, the low-frequency dynamic stiffness is only weakly dependent on frequency due to material properties.

NOTE — For many vibration isolators, static stiffness and low-frequency dynamic transfer stiffness are different.

In principle the dynamic transfer stiffness of vibro-acoustic isolators is dependent on static preload and temperature. In the following theory linearity, as defined in 3.9, 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 vibration isolators

#### 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 isolators under static preload.

The general conceptual framework for the proposed isolator characterization is shown in figure 1.

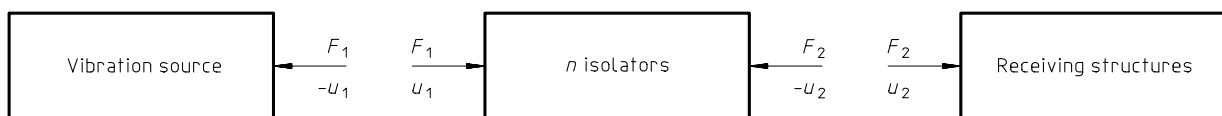


Figure 1 — Block diagram of source/isolators/receiver system

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  $F$  containing three orthogonal forces and three orthogonal moments and a displacement vector  $u$  containing three orthogonal translational and three orthogonal rotational components are assigned. In figure 1 just one component of each of the vectors  $F_1$ ,  $u_1$ ,  $F_2$  and  $u_2$  is shown. These vectors contain  $6n$  elements, where  $n$  denotes the number of isolators.

To show that the blocked transfer stiffness, defined in 3.6 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.



### 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:

$$F_1 = k_{1,1}u_1 + k_{1,2}u_2 \quad (1)$$

$$F_2 = k_{2,1}u_1 + k_{2,2}u_2 \quad (2)$$

where

$k_{1,1}$  and  $k_{2,2}$  are driving point stiffnesses when the isolator is blocked at the opposite side (i.e.  $u_2 = 0$ ,  $u_1 = 0$ , 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 additional 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 — These equations are for single frequencies.  $F_i$  and  $u_i$  are phasors and  $k_{i,j}$  are complex quantities.

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

$$F = [k] u \quad (3)$$

with the dynamic stiffness matrix

$$[k] = \begin{bmatrix} k_{1,1} & k_{1,2} \\ k_{2,1} & k_{2,2} \end{bmatrix} \quad (4)$$

For excitation of the receiving structure via the isolator

$$k_r = -\frac{F_2}{u_2} \quad (5)$$

where  $k_r$  denotes the dynamic driving point stiffness of the receiver. The minus sign is a consequence of the convention adopted in figure 1.

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

$$F_2 = \frac{k_{2,1}}{1 + \frac{k_{2,2}}{k_r}} u_1 \quad (6)$$

Therefore, for a given source displacement  $u_1$ , the force  $F_2$  depends both on the isolator driving point dynamic stiffness and on the receiver driving point dynamic stiffness. However, if  $|k_{2,2}| < 0,1|k_r|$ , then  $F_2$  approximates the so-called blocking force to within 10 %, i.e.

$$F_2 \approx F_{2, \text{blocking}} = k_{2,1} u_1 \quad (7)$$

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 measuring 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 stiffness matrix (or the complete transfer matrix). Moreover it forms the representative isolator characteristic under the intended circumstances.

NOTE — In cases that the condition  $|k_{2,2}| \ll |k_r|$  is not fulfilled, equation (6) also shows that  $k_{2,2}$  and  $k_r$  need to be known to predict  $F_2$  for a given source displacement  $u_1$ .

### 5.2.3 Single isolator, six vibration directions

If forces and motions at each interface can be characterized by six orthogonal components (three translations, three rotations), the isolator may be described as a 12-port [11]. The matrix form of the 12 dynamic stiffness equations is equal to equation (3), where now

$$\mathbf{u} = \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix}, \mathbf{F} = \begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix} \quad (8)$$

are the vectors of the six displacements, six angles of rotations, six forces and six moments. The  $12 \times 12$  dynamic stiffness matrix may be decomposed into four  $6 \times 6$  submatrices

$$[k] = \begin{bmatrix} [k_{1,1}] & [k_{1,2}] \\ [k_{2,1}] & [k_{2,2}] \end{bmatrix} \quad (9)$$

where

$[k_{1,1}]$  and  $[k_{2,2}]$  are (symmetric) matrices of the driving point stiffnesses;

$[k_{1,2}]$  and  $[k_{2,1}]$  are the blocked transfer stiffness matrices.

Reciprocity implies that these transfer matrices equal their transpose.

Again, if the receiver has relatively large driving point dynamic stiffnesses compared to the isolator, the forces exerted on the receiver approximate the blocking forces:

$$F_{2, \text{blocking}} = [k_{2,1}] \cdot u_1 \quad (10)$$

Therefore, the blocked transfer stiffnesses are appropriate quantities to characterize vibro-acoustic transfer properties of isolators, and also in the case of multidirectional vibration transmission.

### 5.3 Number of relevant blocked transfer stiffnesses

For the general case the blocked transfer stiffness matrix  $[k_{2,1}]$  of a single isolator contains 36 elements. However, structural symmetry causes most elements to be zero. The most symmetrical shapes (a circular cylinder or a square block) have 10 non-zero elements, i.e. five different pairs (see annex B and reference [11]).

In practical situations the number of elements relevant for characterization of the vibro-acoustic transfer is usually even smaller than the number of non-zero elements. In many cases it will be sufficient to take into account only one, two or three diagonal elements for translation vibration, i.e. for only one vibration direction (often vertical) or for two or three perpendicular directions (see annex C for further discussion). For these translational directions, measurement methods will be defined in parts 2 to 5 of ISO 10846.

For some special technical cases, rotational degrees of freedom also play a significant role (see annex C). Although it is not considered as a subject for standardization in ISO 10846, reference is made in 6.3.5 to literature that describes how rotational elements may be handled in the same way as the translational elements. ISO 10846-3 and ISO 10846-4 have informative annexes relevant to this subject.

### 5.4 Flanking transmission

The model shown in figure 1 and of equations (1) to (10) is correct under the assumption that the isolators form the only transfer path between the vibration source and the receiving structure. In practice there may be mechanical or acoustical parallel transmission paths which cause flanking transmission. For any measurement method of isolator properties, the possible interference of such flanking with proper measurements has to be minimized.

## 5.5 Loss factor

The objective of ISO 10846 is to standardize measurements of the frequency-dependent dynamic transfer stiffnesses  $k_{2,1}$  of resilient elements. Certain users of ISO 10846 also will be interested in the damping properties of isolators. However, ISO 10846 does not standardize the measurement of damping properties of isolators because this would become overly complex. Nevertheless, in parts 2 to 5 of ISO 10846, descriptions are given of how phase data of the complex dynamic transfer stiffness  $k_{2,1}$  can be optionally used to give information about the damping properties. The discussion in this subclause is given as background information for the procedures.

For the purposes of the discussion it is sufficient to consider the case of 5.2.2, i.e. a single isolator and a single vibration direction. Because only measurements with a blocked output side are considered in ISO 10846, the phasor equations (1) and (2) are reduced to

$$F_1 = k_{1,1}u_1 \quad (11)$$

$$F_2 = k_{2,1}u_1 \quad (12)$$

At low frequencies, where inertial forces (e.g. wave effects) play no role, there is a simple relationship between the phase angle of the dynamic transfer stiffness and the damping properties of the resilient element. At these low frequencies, the frequency-dependent stiffness can be approximated by

$$k \approx k_{1,1} \approx k_{2,1} \quad (13)$$

This complex low-frequency dynamic stiffness can be written as

$$k = k_0(1+i\eta) \quad (14)$$

where  $k_0$  denotes the real part. The frequency-dependent loss factor  $\eta$  in equation (14) characterizes the damping of the resilient element at low frequencies (see 3.7).

The relationship between the loss factor and the phase angle  $\phi$  of  $k$  is given by

$$\eta = \tan \phi \quad (15)$$

Therefore, the loss factor of a resilient element can be estimated according to

$$\eta \approx \tan \phi_{2,1} \quad (16)$$

where  $\phi_{2,1}$  is the phase angle of the dynamic transfer stiffness  $k_{2,1}$ .

The following points should be kept in mind.

- a) The measurement of small loss factors using equation (16), is extremely sensitive to phase measurement errors [12]. However, for rubber-type resilient elements this problem is not critical except at frequencies below a few hertz.
- b) For higher frequencies, where the approximations of equation (13) are no longer valid, it is no longer correct to use equation (16) as a characterization of the damping properties of the resilient element. Although there are no simple and strict criteria for when this occurs, a rather sudden change of the slope of  $\eta$  with increasing frequency is usually a good indication that equation (16) can no longer be used.

## 6 Measurement principles

### 6.1 Dynamic transfer stiffness

The dynamic transfer stiffness is dependent on frequency. In addition it is also dependent on static preload and, in many cases, on temperature. Three methods are in use to obtain the appropriate test data. Because they are complementary with respect to their strong and weak points, they are all described in ISO 10846.