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

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

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

Partie 2: Méthode directe pour la détermination de la raideur dynamique en translation des supports élastiques

Reference number
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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.

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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 10846-2 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 10846-2:1997), 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 resilient elements of various kinds are used to reduce the transmission of vibrations. Examples are 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 specifies a direct method for measuring the dynamic transfer stiffness function of linear resilient supports. This includes resilient supports with non-linear static load-deflection characteristics, as long as the elements show an approximate linearity for vibration behaviour for a given static preload. This part of ISO 10846 belongs to a series of International Standards on methods for the laboratory measurement of vibro-acoustic properties of resilient elements, which also includes documents on measurement principles, on an indirect method and on a driving point method. ISO 10846-1 provides guidance for the selection of the appropriate International Standard.

The laboratory conditions described in this part of ISO 10846 include the application of static preload.

The results of the method described in this part of ISO 10846 are useful for resilient supports that are used to prevent low-frequency vibration problems and to attenuate structure-borne sound in the lower part of the audible frequency range. 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 this method.

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

Part 2:

Direct method for determination of the dynamic stiffness of resilient supports for translatory motion

1 Scope

This part of ISO 10846 specifies a method for determining the dynamic transfer stiffness for translations of resilient supports, under specified preload. The method concerns the laboratory measurement of vibrations on the input side and blocking output forces and is called “the direct method”. The method is applicable to test elements with parallel flanges (see Figure 1).

Resilient elements, which are the subject of this part of ISO 10846, are those which are used to reduce

— the transmission of vibration in the lower part of the audible frequency range (typically 20 Hz to 500 Hz) to a structure which may, for example, radiate unwanted fluid-borne sound (airborne, waterborne or others), and

— 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 vibration is too severe.

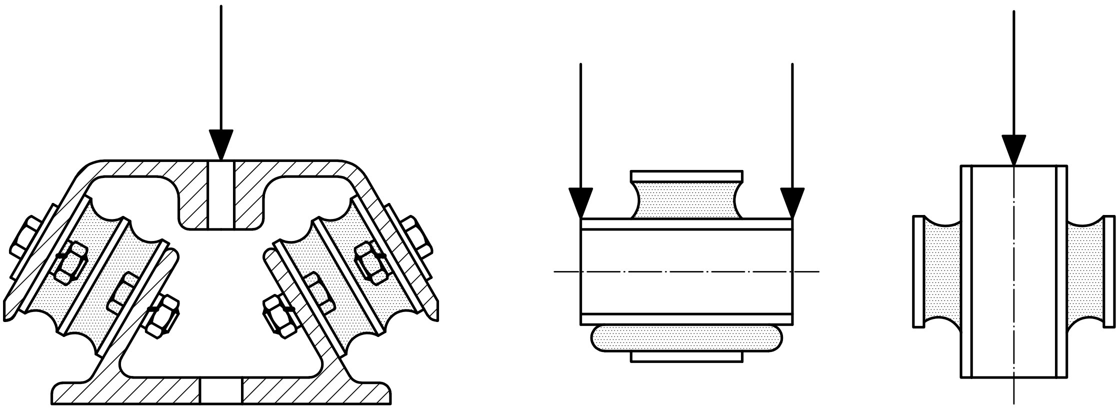
NOTE 1 In practice, the size of the available test rig(s) can restrict the use of very small or very large resilient supports.

NOTE 2 Samples of continuous supports of strips and mats are included in this method. Whether or not the sample describes the behaviour of the complex system sufficiently is the responsibility of the user of this part of ISO 10846.

Measurements for translations normal and transverse to the flanges are covered in this part of ISO 10846.

The direct method covers the frequency range from 1 Hz up to a frequency f_{UL}, which is usually determined by the test rig.

NOTE 3 Because of the large variety of test rigs and test elements, f_{UL} is variable. In this part of ISO 10846, the adequacy of the test rig is not defined for a fixed frequency range, but on the basis of measured data, as described in 6.1 to 6.4.



NOTE 1 When a resilient support has no parallel flanges, an auxiliary fixture is included as part of the test element to arrange for parallel flanges.

NOTE 2 The arrows indicate the load direction.

Figure 1 — Example of resilient supports with parallel flanges

The data obtained according to the method specified in this part of ISO 10846 can be used for the following:

- product information provided by manufacturers and suppliers;
- information during product development;
- quality control;
- calculation of the transfer of vibration energy through isolators.

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 266, *Acoustics — Preferred frequencies*

ISO 2041:—1), *Mechanical vibration, shock and condition monitoring — Vocabulary*

ISO 5348, *Mechanical vibration and shock — Mechanical mounting of accelerometers*

ISO 7626-1, *Vibration and shock — Experimental determination of mechanical mobility — Part 1: Basic definitions and transducers*

ISO 10846-1, *Acoustics and vibration — Laboratory measurement of vibro-acoustic transfer properties of resilient elements — Part 1: Principles and guidelines*

ISO 16063-21, *Methods for the calibration of vibration and shock transducers — Part 21: Vibration calibration by comparison to a reference transducer*

ISO/IEC Guide 98-32), *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement* (*GUM 1995*)

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

2) ISO/IEC Guide 98-3 will be published as a re-issue of the *Guide to 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 support 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 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, relative humidity and other conditions.

NOTE 3 At low frequencies, $k_{2,1}$ is solely determined by elastic and dissipative forces and $k_{1,1} \approx k_{2,1}$ ($k_{1,1}$ denotes the ratio of force and displacement on the input side). At higher frequencies, inertial forces in the resilient element play a role as well and $k_{1,1} \neq k_{2,1}$.

3.6

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

3.7

frequency-averaged dynamic transfer stiffness

k_av

function of the frequency of the average value of the dynamic transfer stiffness over a frequency band Δf

NOTE See 8.2.

3.8

point contact

contact area that vibrates as the surface of a rigid body

3.9
normal translation

translational vibration normal to the flange of a resilient element

3.10
transverse translation

translational vibration in a direction perpendicular to that of the normal translation

3.11
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 $ax_1(t) + bx_2(t)$ produces the output $ay_1(t) + by_2(t)$. 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 (see 7.7).

3.12
direct method

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

3.13
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 known mass

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

3.14
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

3.15
force level

L_F

level defined by the following formula

$$L_F = 10 \lg \frac{F^2}{F_0^2} \text{ dB}$$

where

F^2 denotes the mean square value of the force in a specific frequency band and F_0 is the reference force ($F_0 = 10^{-6}$ N)

3.16

acceleration level

L_a

level defined by the following formula

$$L_a = 10 \lg \frac{a^2}{a_0^2} \text{ dB}$$

where

a^2 denotes the mean square value of the acceleration in a specific frequency band and a_0 is the reference acceleration ($a_0 = 10^{-6}$ m/s^2)

3.17

level of dynamic transfer stiffness

$L_{k_{2,1}}$

level defined by the following formula

$$L_{k_{2,1}} = 10 \lg \frac{\left| k_{2,1} \right|^2}{k_0^2} \text{ dB}$$

where

$|k_{2,1}|^2$ is the square magnitude of the dynamic transfer stiffness (3.5) at a specified frequency and k_0 is the reference stiffness (k_0 = 1 N/m)

3.18

level of frequency-band-averaged dynamic transfer stiffness

$L_{k_{\text{av}}}$

level defined by the following formula

$$L_{k_{\text{av}}} = 10 \lg \frac{k_{\text{av}}^2}{k_0^2} \text{ dB}$$

where

k_{av} is the frequency-averaged dynamic transfer stiffness (3.7) and k_0 is the reference stiffness (k_0 = 1 N/m)

3.19

flanking transmission

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

3.20

upper limiting frequency

f_{UL}

frequency up to which the results are valid, according to the criteria given in this part of ISO 10846

NOTE See 6.1 to 6.4.

4 Principle

The measurement principle of the direct method for measuring the dynamic transfer stiffness (3.5) is discussed in ISO 10846-1. The characteristic feature of this method is that the blocking output force is measured between the output side of the resilient support and a foundation. The foundation must provide a sufficient reduction of the vibrations on the output side of the test object compared to those on the input side.

5 Requirements for apparatus

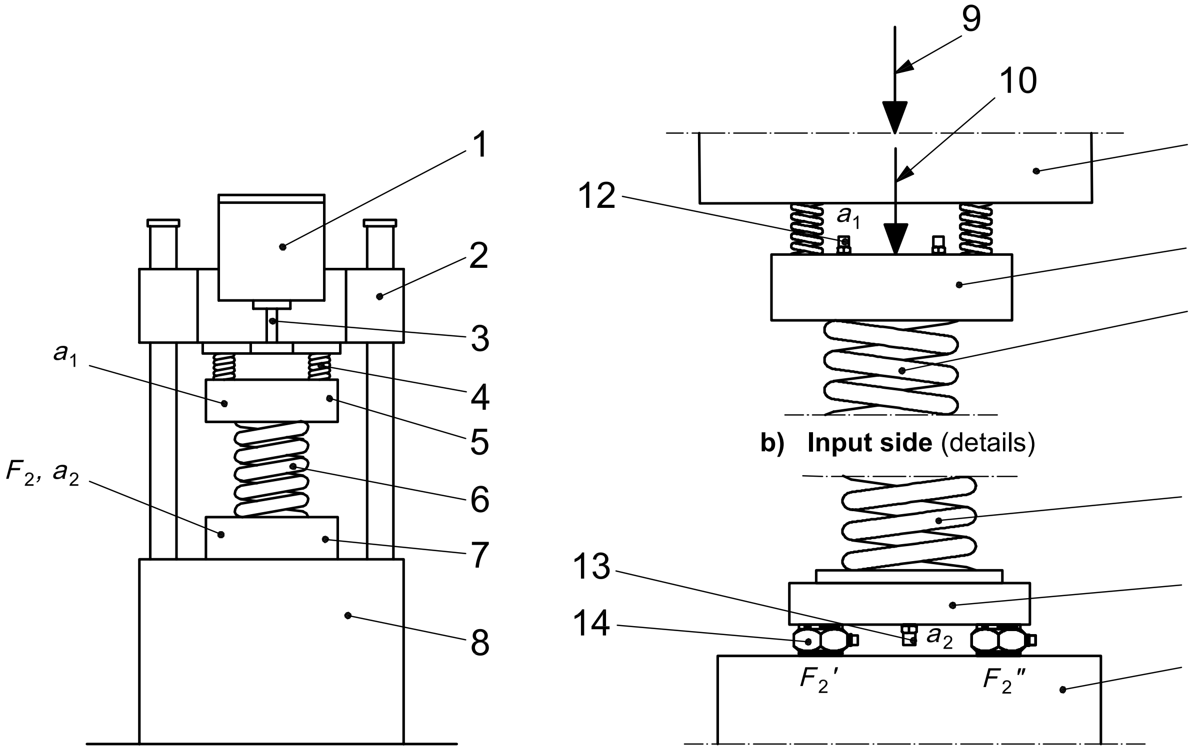
5.1 Normal translations

5.1.1 Overview

A schematic representation of a test rig is shown in Figure 2. The test element is exposed to translatory vibration in the normal load direction. The test element shall be mounted in a way that is representative of its use in practice.

NOTE The test rig example of Figure 2 is not intended to form a limitation for test arrangements.

To be suitable for the measurements according to this part of ISO 10846, a test rig shall include the items described in 5.1.2 to 5.1.7.



b) **Input side** (details)

a) **Overview**

c) **Output side** (details)

Key

1	vibration exciter
2	traverse
3	connection rod
4	dynamic decoupling springs, static preload
5	excitation mass
6	test element
7	output force and acceleration measurement
8	rigid foundation
9	static preload
10	dynamic excitation
11	output-force distribution plate
12	input acceleration measurement (a_1)
13	output acceleration measurement (a_2)
14	normal output-force measurement $\left(F_2 = F_2' + F_2''\right)$

Figure 2 — Example of laboratory test rig for measuring the dynamic transfer stiffness for normal translations

5.1.2 Foundation

The test element is mounted on a heavy and rigid foundation using a force measurement system [see 5.1.4 and Figure 2 c)].

5.1.3 Static preloading system

Measurements shall be performed with the test element under a representative and specified preload. Examples of methods for applying the static preload are as follows.

a) Use of a hydraulic actuator, which serves also as a vibration exciter. This is mounted in a load frame, together with the test element and the foundation table.

b) Use of a frame, which provides static preload only; see Figure 2 a). If such a frame is applied, auxiliary vibration isolators shall be used for dynamic decoupling of the test object from the frame.

c) Use of a gravity load using a mass on top of the test object (with or without a support frame).

5.1.4 Force measurement system on the output side

A force measurement system consisting of one or more force transducers (load cells) shall be installed on the output side of the test element; see Figure 2 c).

NOTE It might be necessary to apply a force distribution plate between the test element and the force transducers. Besides its function of load distribution, the force distribution plate also provides a high contact stiffness to the force transducers. Moreover, it provides a uniform vibration of the output flange.

5.1.5 Acceleration measurement systems

Accelerometers shall be mounted on the input and output side of the test element and on the foundation of the test arrangement; see Figures 2 b) and 2 c). When mid-point positions are not accessible, indirect measurement of mid-point accelerations shall be performed by making an appropriate signal summation, for example, by taking the linear average for two symmetrically positioned accelerometers.

As an option, instead of accelerometers, displacement or velocity transducers may be used, provided that their frequency range is appropriate.

5.1.6 Dynamic excitation system

The dynamic excitation system shall be suitable for the excitation level and for the frequency range of interest. Any type of exciter is permitted. Examples are

a) a hydraulic actuator which also can provide a static preload, or

b) one or more electrodynamic vibration exciters (shakers) with connection rods, or

c) one or more piezo-electric exciters.

Vibration isolators may be used for dynamic decoupling of exciters, to reduce flanking transmission via the frame for applying static preload. However, in the test rigs that use a hydraulic actuator for both static and dynamic loading, such a decoupling is usually inconvenient because of its adverse effects on low-frequency measurements.

5.1.7 Excitation mass on the input side

The excitation mass or force distribution plate on the input side of the test object has one or more of the following functions:

a) to provide a uniform vibration of the input flange under dynamic forces;

b) to enhance unidirectional vibration of the input flange.

If the test element contains a solid-mass-type input flange, which can provide the above-mentioned functions, the special excitation mass may be omitted.

5.2 Transverse translations

5.2.1 Overview

Schematic representations of test rigs for resilient supports exposed to transverse vibrations perpendicular to the normal load direction are shown in Figures 3 to 5. In Figures 3 a) and 3 c), roller bearings are used, respectively for suppressing unwanted input vibrations and for suppressing unwanted transverse forces on the output-force distribution plate. See 5.2.7 and 6.1 for further comments on the proper use of such bearings. In Figures 4 and 5 two symmetrically placed nominally equal resilient elements are used for suppressing unwanted input vibrations.

The test rig shall include the items listed in 5.2.2 to 5.2.7.

5.2.2 Foundation

The test element is mounted on a heavy and rigid foundation table (see Figures 3 and 4) or between stiff columns (see Figure 5), using a force measurement system.

5.2.3 Static preloading system

Measurements shall be performed with the test element under a representative and specified preload. Figures 3 to 5 present some schematic examples.

5.2.4 Force measurement system on the output side

A force measurement system consisting of one or more force transducers (load cells) shall be installed on the output side of the test element. Two basic options exist.

a) One or more force transducers for the measurement of shear forces; see Figures 3 d), 4 and 5. It may be necessary to apply a force distribution plate between the test element and the force transducers (see the notes in 5.1.4),

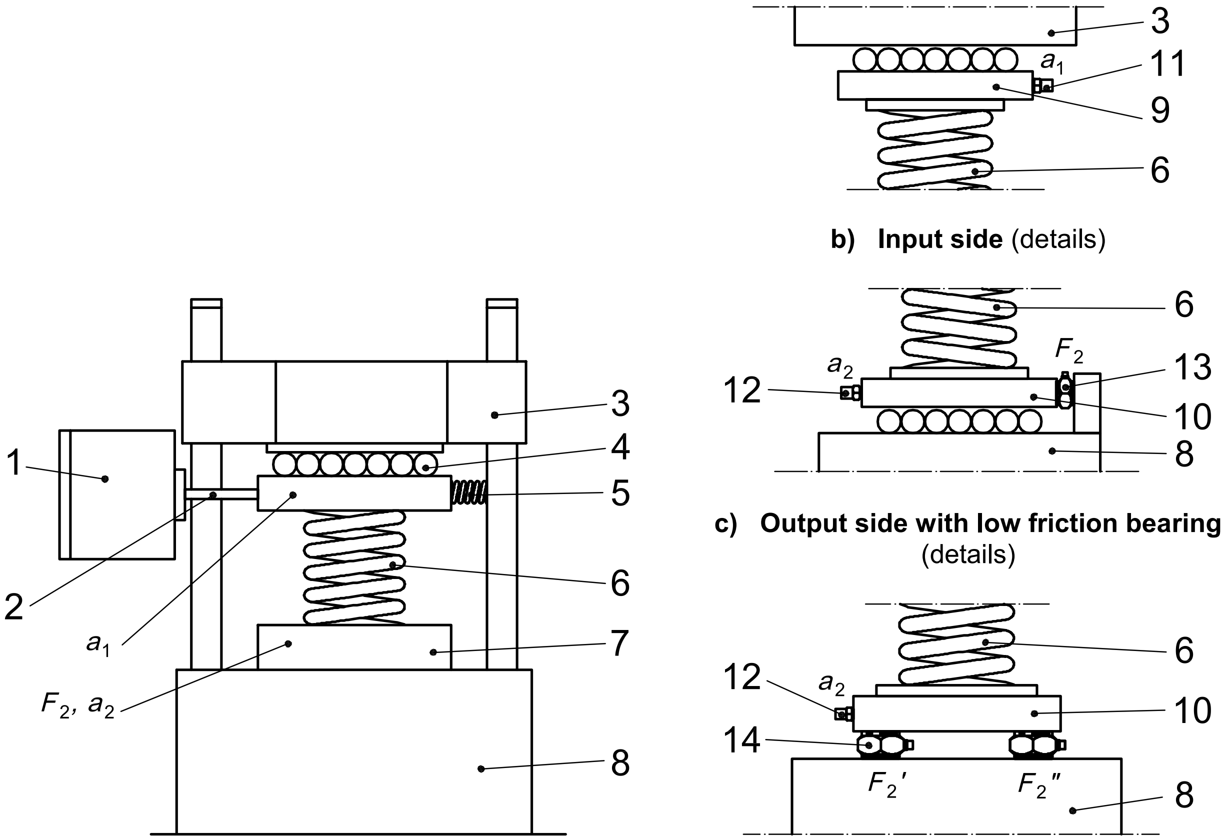
b) One or more normal force transducers; see Figure 3 c). It may be necessary to apply a force distribution plate between the test element and the force transducers; see the note in 5.1.4.

5.2.5 Acceleration measurement systems on the input and output sides

Accelerometers shall be mounted on the input and output side of the test element.

The accelerometers on the test element flanges or on the force distribution plate may be placed on horizontal symmetry axes of these components. When such places are not accessible, indirect measurement of the acceleration along a symmetry axis may be performed by making an appropriate signal summation, for example, by taking the linear average for two symmetrically positioned accelerometers.

Provided that displacement or velocity transducers have the appropriate frequency response, they may be used instead of accelerometers.



b) **Input side** (details)

a) **Overview**

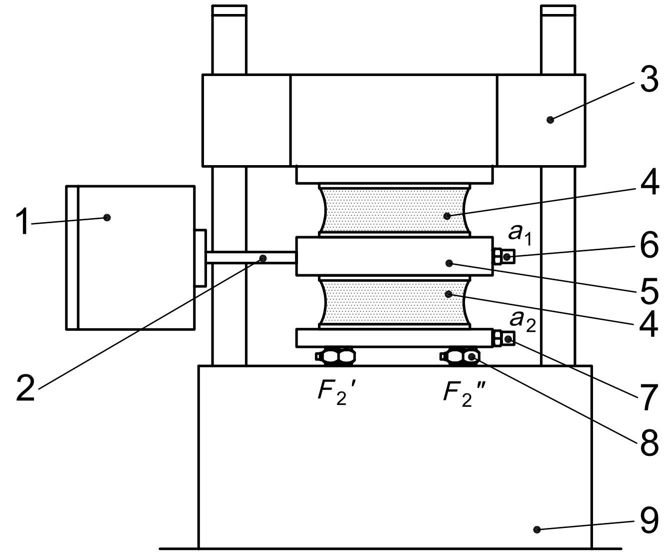
c) Output side with low friction bearing (details)

d) Output with shear force transducers (details)

Key

1 exciter
2 connection rod
3 traverse
4 low-friction bearing
5 auxiliary springs to prevent rattling
6 test element
7 output force and acceleration measurement
8 rigid foundation
9 input-force distribution plate (excitation mass)
10 output-force distribution plate
11 input acceleration measurement (a_1)
12 output acceleration measurement (a_2)
13 output transverse-force measurement (F_2)
14 output shear-force measurement $\left(F_2 = F_2' + F_2''\right)$

Figure 3 — Example 1 of laboratory test rig for measuring the dynamic transfer stiffness for transverse translation



Key

1 exciter

2 connection rod

3 traverse

4 nominally equal resilient elements

5 input-force distribution plate

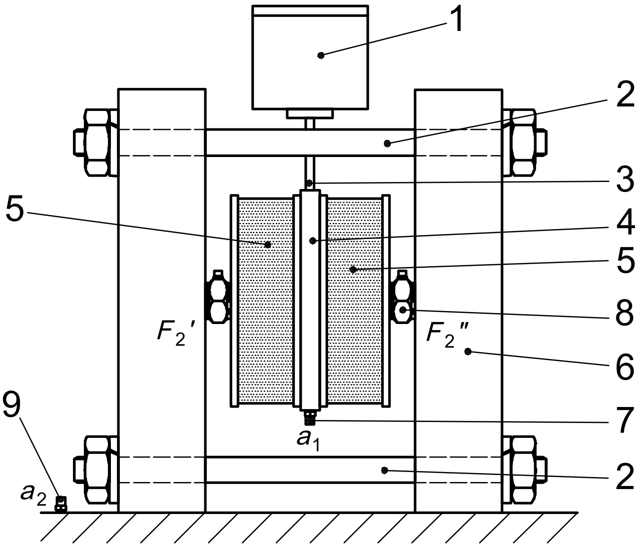
6 input acceleration measurement (a_1)

7 output acceleration measurement (a_2)

8 output shear-force measurement $\left(F_2 = F_2' + F_2''\right)$

9 rigid foundation

Figure 4 — Example 2 of laboratory test rig for measuring the dynamic transfer stiffness for transverse translation (The lower resilient element is considered as the test element)



Key

1 exciter

2 preloading device

3 connection rod

4 input-force distribution plate

5 nominally equal test elements

6 rigid columns

7 input acceleration measurement (a_1)

8 output shear-force measurement [F_2 = (F_2' + F_2'')/2]

9 output acceleration measurement (a_2)

Figure 5 — Example 3 of laboratory test rigs for measuring the dynamic transfer stiffness for transverse translation (Test results are for the average transfer stiffness of two nominally equal resilient elements)

5.2.6 Dynamic excitation system

The dynamic excitation system shall be suitable for the excitation level and frequency range of interest. Examples of vibration exciters are given in 5.1.6.

5.2.7 Excitation mass on the input side

The Input-force distribution plate (mass) has one or more of the following functions:

a) to provide a uniform vibration of the input flange under dynamic forces

b) to enhance unidirectional vibration of the input flange.

If the test element contains a solid-mass-type input flange, which can provide the above-mentioned functions, the special excitation mass can be omitted.

Predominantly unidirectional translation on the input side of the test element is an essential requirement for the measurement of dynamic stiffness according to this part of ISO 10846 (see 6.4). For input translations, predominance of the required translation will be influenced by

a) the symmetry of the vibration excitations and boundary conditions of the excitation mass (see Figures 4 and 5), and

b) the inertial properties of the excitation mass.

In certain cases, it will be necessary to apply external constraints, such as low-friction bearings or some other guiding system, to prevent vibrations in unwanted directions; see Figures 3 a) and 3 b).

NOTE When, as in the example of Figures 3 a) and 3 b), roller bearings are used between the input side of the test element and a frame for preloading, the appropriate roller bearings for the applied static preload are necessary. Any elastic deformation of the bearings, leading to unwanted transverse forces due to the bearing system, needs to be avoided. Otherwise flanking transmission via the frame structure will occur. This can lead to invalid measurements due to the serious limitation of the frequency range.

5.3 Suppression of unwanted vibrations

5.3.1 General

The test procedures according to this part of ISO 10846 cover measurements of transfer stiffness for unidirectional excitations, one by one in the normal and transverse directions.

However, due to asymmetries in excitation, boundary conditions and test element properties, components other than the intended input vibration component may show unwanted strong responses at certain frequencies. Qualitative measures to suppress unwanted input vibrations are discussed in 5.3.2 and 5.3.3. A special category of test arrangements is that in which two nominally equal resilient elements are tested in a symmetrical configuration; see Figures 4 and 5. This may help to suppress unwanted input vibrations. Quantitative requirements are given in 6.4.

5.3.2 Normal direction

For excitation in the normal direction, a symmetrical positioning of the exciter, or a pair of exciters, shall be the favourable method for suppressing transverse and rotational vibrations on the input side.

Nevertheless, the properties of the test object itself may cause coupling between the normal and other vibration directions. A method of suppressing unwanted input vibrations is the use of a symmetrical arrangement with two or four nominally identical test elements, or using a “guiding” system on the sides of the excitation mass, for example roller bearings. These systems are not shown in a figure.

5.3.3 Transverse direction

For excitation in the transverse direction, coupling between transverse and rotational input vibrations will always occur.

In Figures 3 to 5, examples of measures are shown, which may enhance unidirectional vibrations on the input side. Figure 3 shows an example of how a guiding system can be used to suppress input rotations. Figures 4 and 5 show symmetrical arrangements with two nominally equal test objects.

In the test set-up of Figure 4, the lower resilient element is the test element.

In the test set-up of Figure 5, the average transfer stiffness of the two resilient elements is determined by measuring the average blocking force $F_\mathrm{b} = (F'_\mathrm{b} + F''_\mathrm{b})/2$. It is the responsibility of the user of this part of ISO 10846 to ascertain that the two test elements are nominally equal.

An alternative to the application of conventional methods might be the use of active vibration control. Using multiple actuators and sensors in combination with a control system, the ratio between wanted and unwanted input vibration levels can be improved [6].

6 Criteria for adequacy of the test arrangement

6.1 Frequency range

Each test facility has a limited frequency range in which valid tests can be performed. One limitation is given by the usable bandwidth of the vibration actuator. Another limitation follows from the requirements for measuring the blocking output force. In Figures 2, 3 and 4, the following dynamic measurement quantities are given:

— F_b blocking output force;

— a_1 acceleration of input flange and input-force distribution plate;

— a_2 acceleration of output flange and output-force distribution plate.

The transfer stiffness measurements according to this part of ISO 10846 are valid only for those frequencies where

$$\Delta L_{1,2} = L_{a_1} - L_{a_2} \geqslant 20\,\mathrm{dB} \tag{1}$$

NOTE A level-difference value ($\Delta L_{1,2}$) that is too small can be explained by an insufficient stiffness mismatch between the test element and the foundation, or by flanking transmission via the traverse and the columns to the output side of the test elements or via the air. The use of vibration isolators to decouple the top of the test element from the load frame (see Figure 2), and also to decouple the vibration exciter from the frame, would reduce flanking transmission significantly. See the note in 5.2.7 on the risk of improper application of roller bearings on the input side of the test element.

6.2 Measurement of blocking force

The mass between the test isolator and the output-force transducers causes a bias error in the measurement of the blocking force. Using the symbols in Figure 6, the difference between the approximated blocking force F'_b and the measured force F_b is equal to the inertia force $m_2 a_2$.

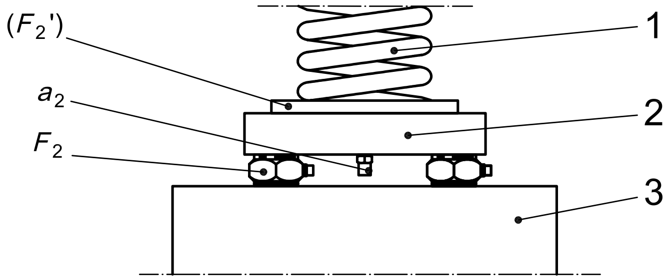
The mass m_2 is the sum of the mass of the output-force distribution plate and half the mass of the force transducers and shall respect the following inequality:

$$m_2 \leqslant 0{,}06 \times \frac{10^{L_{F2}/20}}{10^{L_{a2}/20}}\,\mathrm{kg} \tag{2}$$

NOTE 1 Inequality (2) is equivalent to the requirement that $L_{F_2'} - L_{F_2} \leqslant 0{,}5\ \text{dB}$.

NOTE 2 If Inequality (2) is not respected then either a decrease of m_2 or an increase of force transducer(s) stiffness is needed. The latter may imply the use of more transducers or a larger transducer.

NOTE 3 When, as in the example of Figure 3 c), a roller bearing is used on the output side of the test element, the roller bearing needs to be appropriate for the applied static preload. Elastic deformation of the bearing, leading to unwanted transverse forces due to the bearing system, needs to be avoided.



Key

1 test element

2 output-force distribution plate

3 rigid foundation

Figure 6 — Force and acceleration on output side of the vibration isolator

6.3 Flanking transmission

In many test arrangements, flanking transmission can limit the applicability or accuracy of the test method. The flanking transmission can be caused by airborne sound or structure-borne sound. Given the large variety of test arrangements which are allowed, it is in the interest of the user of this part of ISO 10846 to use test rigs that are robust against invalid measurements caused by flanking transmission. However, obeying Inequality (2) is sufficient for the validity of test results, also in the presence of flanking transmission.

6.4 Unwanted input vibrations

Input accelerations in directions other than those of the excitation shall be suppressed according to 5.3. Measurements according to this part of ISO 10846 are only valid when the level of the input acceleration in the excitation direction exceeds that in the other directions perpendicular to it by at least 15 dB, i.e.

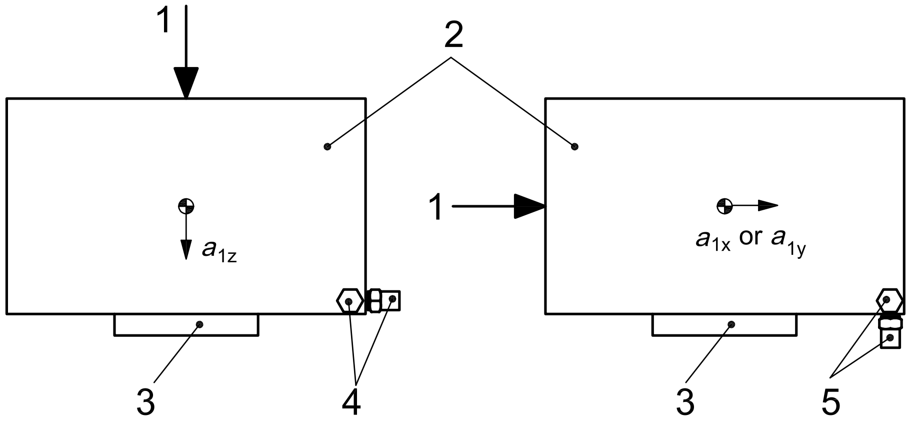
$$L_{a(\text{excitation})} - L_{a(\text{unwanted})} \geqslant 15\ \text{dB} \tag{3}$$

The measurement positions where this requirement shall hold are shown in Figure 7.

For normal excitation, the input vibration in the excitation direction a_{1z} is along the line of excitation, and at the interface between the excitation mass and the input flange. The unwanted inputs in transverse directions a'_{1x} and a'_{1y} shall be measured at the edge of the excitation mass or force distribution plate and in the plane of the interface between the excitation mass and the input flange; see Figure 7.

For transverse excitation (x- or y-direction), the input vibration in the excitation direction (a_{1x} or a_{1y}) is measured along a horizontal symmetry axis of the excitation mass. The unwanted inputs a'_{1z} and a'_{1y} or a'_{1x} shall be measured at the edge of the excitation mass and in the plane of the interface with the input flange.

When the mass-type input flange of the test object replaces the excitation mass (see 5.2.7), a configuration similar to that in Figure 7 shall be defined, to test the adequacy of the suppression of unwanted inputs according to Inequality (3).



Key

1 exciter
2 excitation mass
3 input flange of test element
4 unwanted vibrations a'_{1x} and a'_{1y}
5 unwanted vibrations a'_{1z} and a'_{1y} or a'_{1x}

Figure 7 — Measurement locations for checking the suppression of unwanted input vibrations

6.5 Accelerometers

Accelerometers shall be calibrated at the laboratory temperature in the frequency range of interest and shall have a sensitivity level which is frequency independent within 0,5 dB. Calibration shall be carried out according to ISO 16063-21.

The accelerometers shall be sufficiently unaffected by extraneous environmental effects, such as relative humidity, magnetic fields, electrical fields, acoustical fields and strain, and the sensitivity to cross-axis accelerations shall be smaller than 5 % of the main axis of sensitivity.

If displacement or velocity transducers are used, the same requirements as for accelerometers apply.

6.6 Force transducers

Force transducers shall be calibrated at the laboratory temperature in the frequency range of interest and have a sensitivity level which is frequency independent within 0,5 dB. Calibration shall be carried out according to the mass-loading technique as described in ISO 7626-1.

If there is an appropriate compensation routine (i.e. digital application of an appropriate transfer function), the resultant sensitivity-level function shall meet the 0,5 dB requirement.

The force transducers shall be sufficiently unaffected by extraneous environmental effects, such as relative humidity, magnetic fields, electrical fields, acoustical fields and strain, and the sensitivity to cross-axis forces shall be smaller than 5 % of the main axis of sensitivity.

6.7 Summation of signals

If signals from force transducers or from accelerometers are added, this shall be performed with a maximum tolerance of 5 %. One way to achieve this is to use identical transducers with sensitivities within 5 % of each other. Another way is to perform the summation with the aid of a multi-channel analyser. In that case, corrections shall be made to compensate both for differences in transducer sensitivities and for differences in channel gain factors (see 6.8).

6.8 Analysers

Narrow-band analysers shall be used which fulfil the following requirements.

a) In the frequency range of interest, the spectral resolution shall provide at least five distinct frequencies per one-third-octave band;

b) The difference in frequency responses between the channels (including signal-conditioning equipment), which are used for the acceleration measurement on the input side, and for the force measurement on the output side, shall be less than 0,5 dB for a measurement with the same frequency resolution as used for testing the resilient support. Otherwise, corrections shall be made to compensate for the differences in channel gain factors.

One way in which channel gains may be compared is as follows: An identical broadband signal (e.g. white noise) is applied as input to both channels. Then the narrow-band spectrum of the magnitude of the output ratio should be less than 0,5 dB, otherwise the measured gain ratio needs to be used as a correction factor for the measured dynamic stiffness.

7 Test procedures

7.1 Installation of the test elements

The test element is attached to the excitation mass (or Input-force distribution plate) and to the output-force distribution plate (if any), in a way that ensures good contact over the entire surface of the flanges. Devices that are not part of the resilient element in practical applications shall be de-activated and removed.

NOTE To improve contact between the resilient test element and the adjacent test rig components, grease or double-sided tape can be added. However, in the latter case, problems can occur in the high-frequency range. For test elements with big flanges, flattening might be necessary to obtain unambiguous test results.

Test elements, which contain rubber-type components, will show a change of load or deflection due to creep. For such objects, preloading shall be applied to 100 % of the permissible static load. A change of load or deflection due to creep should be less than 10 % per day before measurements are performed.

7.2 Selection of force measurement system and output-force distribution plates

Depending upon the size and symmetry of the test isolator and on the maximum permissible load, one or more force transducers are applied.

The output-force distribution plate shall be as small and as light as possible, but rigid enough to avoid resonances of the system occurring in the frequency range of interest. The minimum lateral dimension is determined by the size of the test object.

To check the rigid body behaviour of the force measurement system, excite the system with a point force in the centre. The transfer function determined from this point force (measured with a calibrated force transducer) and the output signal of the force measurement system shall be flat in the frequency range of interest.

7.3 Mounting and connection of accelerometers

Accelerometers shall be mounted on the input and output sides of the test element, to measure a_1 and a_2, respectively (see Figures 2 to 5). The connection shall be rigid. Mounting shall be carried out in accordance with ISO 5348.

Positions where sensors are to be placed on the force distribution plates, or on the flanges of the test object, shall be carefully selected. If the vibration is predominantly in the vertical direction or the transverse direction, a single accelerometer, usually at a position outside the axis of symmetry, may be sufficient. In case of such a measurement, it shall be checked that the influence of rotational vibration does not lead to deviations of more than 0,5 dB.

NOTE Measuring the accelerations at different distances from the symmetry axis can perform the check on rotational vibration.

To prevent deviations due to flange rotations, the signals from two accelerometers that are positioned symmetrically with respect to the vertical symmetry axis may be averaged.

7.4 Mounting and connections of the vibration exciter

A connection rod may be necessary between the vibration source and the input side of the test element, such as described in [3]. It shall be designed in such a way that strong transverse vibration and sound radiation are avoided due to resonance of this rod.

7.5 Source signal

One of the following source signals may be used:

- a discretely stepped sinusoidal signal;
- a swept sine signal;
- a periodically swept sine signal, or
- a bandwidth-limited noise signal.

The source signal shall be applied sufficiently long to allow for averaging such that the measured results do not differ by more than 0,1 dB when the averaging time is doubled. When discretely stepped sinusoidal signals or periodically swept sine signals are used, the spacing of the frequencies of the source signal shall be such that each one-third-octave band for which stiffness data are determined contains at least five frequencies of the source signal.

7.6 Measurements

7.6.1 General

The measurements shall be carried out under one or more specified load conditions, representing the range of loads in practice.

The measurements shall be carried out under one or more specified environmental temperatures, representing the range of the environmental temperatures in practice. The environmental temperature shall be monitored during the measurements. The resilient elements under test shall be exposed for at least 24 h to the appropriate environmental temperature within a tolerance of 3 °C, before testing.

If it is known or if it is reasonable to expect that the dynamic stiffness of the element under test is very sensitive to changes in temperature or humidity, tolerances for the temperature and humidity shall be defined, within which the measurement results are considered as valid.

In a pre-run, the force level L_{F_2} and the acceleration level L_{a_1} shall be determined with and without the vibration source in operation. If possible, and unless otherwise specified, the source output shall be adjusted to obtain a minimum level difference of 15 dB in all frequency bands of interest, compared to measurements with the source switched off.

A further pre-run shall be performed to check that the acceleration in the excitation direction exceeds the acceleration in other directions. Measurement results, which do not meet the condition of 6.1, Inequality (1), shall be excluded from the evaluation of the dynamic stiffness function.

Another pre-run shall be performed to check the appropriate accelerometer positions, when single accelerometers are used for measuring a_1 and a_2.

The main measurements shall be carried out for the acceleration a_{1x}, a_{1y} and a_{1z} on the input side of the test object, for the force F_2 on the output side, and for the acceleration a_{2x}, a_{2y} or a_{2z} on the output side. The z-direction corresponds with the normal direction and the x- and y- directions with the perpendicular transverse directions. Measurement results, which do not meet the requirements of 6.1 and 6.4, shall be excluded from the evaluation of the dynamic stiffness function.

7.6.2 Validity of the measurements

Conditions for the validity of the measurement method are the following:

a) approximate linearity of the vibration behaviour of the isolator (see 7.7);

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

NOTE Observation of the coherence function between the appropriate input and output signals is useful, because its value is indicative of low signal-to-noise ratio, non-linearities, or other causes reducing the measurement precision.

7.6.3 Measurement uncertainty

The uncertainty of results obtained from the measurements according to this part of ISO 10846 shall be evaluated, preferably in compliance with ISO/IEC Guide 98-3. If reported, the expanded uncertainty, together with the corresponding coverage factor for a stated coverage probability of 95% as defined in ISO/IEC Guide 98-3, shall be given.

Guidance on the evaluation of uncertainty and on the determination of the expanded uncertainty is given in Annex B.

NOTE Full application of ISO/IEC Guide 98-3 for determination of the expanded uncertainty is not expected to be possible at present, except for a few specialized laboratories. The existing knowledge on (possible) major uncertainty contributions and on reproducibility data is considered insufficient for the time being. Systematic investigations of the various sources of uncertainty as described in Annex B are needed to improve this situation. However, given the large variety of test elements and test apparatus and the limited funding for such investigations, progress on this item is expected to be slow.

7.7 Test for linearity

In the ISO 10846 series, the concept of dynamic transfer stiffness and the methods to measure it are based upon linear models for the vibration behaviour of resilient elements. However, real vibration isolators show, at best, only approximately linear behaviour. Therefore, to define precisely what is accepted in this part of ISO 10846 as being approximately linear, the validity of dynamic transfer stiffness data in relation to input vibration levels is considered.

Because a full test of linearity is impractical, data measured according to this part of ISO 10846 shall be checked with respect to the degree of proportionality between the output and input, in terms of the ratio of force output to the input acceleration (or velocity, or displacement); see 3.11, Notes 1 and 2.

The validity of dynamic transfer stiffness data measured according to this part of ISO 10846 may only be claimed for input amplitudes, which are equal to or lower than those applied in the tests, and for which an approximate proportionality between output and input has been proved. This upper bound of input levels, for which valid data may be claimed, shall be specified in the test report.

For the proportionality test, the following procedure shall be applied.

a) Let A be a one-third-octave-band spectrum of input levels.

b) Let B be another input spectrum, with one-third-octave-band levels at least 10 dB lower than A.

c) If the transfer stiffness levels for both excitation spectra A and B do not differ by more than 1,5 dB, then the transfer stiffness data shall be considered as valid in the range of input levels (or corresponding input amplitudes) equal to or smaller than those of A.

d) If the maximum levels of A, which are possible in the test rig, are lower than the typical input levels in practical applications of the tested elements, the test rig has to be modified or another test rig shall be used in order to obtain valid data for those applications.

e) If the tests, as described under c), lead to unacceptable results, the tests shall be repeated with lower input levels, until a valid input level range has been determined for proportionality between the output and the input vibration amplitudes.

The range of valid input levels shall be specified as the values of the one-third-octave-band levels of the input accelerations (or displacements if input displacements have been measured) which are equal to or lower than those in the test with the higher input levels and with valid results.

NOTE On the basis of this upper limit of input levels, simplified information can be derived which can be presented optionally. For example, this can be a maximum of r.m.s. input displacement.

If a test element fails to meet the above-mentioned criteria for proportionality between input and output vibration amplitudes, it shall be considered non-linear. This part of ISO 10846 does not provide a measurement procedure for such cases. Nevertheless, large parts of it can still be used to define application-oriented test procedures (e.g. for sinusoidal excitations with specified amplitudes).

8 Evaluation of test results

8.1 Calculation of dynamic transfer stiffness

When blocking forces F_2 and accelerations a_1 have been measured, the calculation of dynamic transfer stiffness requires conversion of accelerations to displacements.

For simple harmonic vibration and using phasor notation,

$$k_{2,1} = \frac{\underline{F}_2}{\underline{u}_1} = -(2\pi f)^2 \frac{\underline{F}_2}{\underline{a}_1} \tag{4}$$

The dynamic transfer stiffness is a complex quantity with magnitude $\left|k_{2,1}\right|$ and phase angle $\varphi_{2,1}(f)$.

Within the same limitations and additional requirements on the measurement precision, which provide the vibration transmissibility $k_{2,1}$, the loss factor η of the test element is calculated in accordance with 3.6 from

$$\eta = \tan \varphi_{2,1} = \mathrm{Im}\left\{k_{2,1}\right\} / \mathrm{Re}\left\{k_{2,1}\right\} \tag{5}$$

NOTE 1 The evaluation of the loss factor is optional. For higher frequencies, the test element no longer behaves as a massless spring. Therefore, it is no longer correct to use Equation (5) as a characterization of the damping properties of the resilient element (see ISO 10846-1).

NOTE 2 If the loss factor is very small, then the use of Equation (5) will become very sensitive to errors. For example, a loss factor η = 0,01 corresponds to a phase angle $\varphi_{2,1}$ = arctan η = 0,57°. In such cases, it is recommended to design a test with a so-called half-value bandwidth method.

8.2 One-third-octave-band values of the frequency-averaged dynamic transfer stiffness

One-third-octave-band averages of $k_{2,1}$ are obtained as follows:

$$k_{\mathrm{av}} = \left\{ \frac{1}{n} \sum_{i=1}^{n} \left| k_{2,1}(f_i) \right|^2 \right\}^{1/2} \tag{6}$$

where the summation is performed over a minimum of $n = 5$ frequencies.

NOTE 1 Averaging over the squared magnitude is chosen to emphasize the maxima in the stiffness values, which usually are the most important ones.

NOTE 2 The result of Equation (6) is consistent with the frequency-averaged result measured directly with a real time one-third-octave-band analyser, in the case of a flat power spectral-density function of the input displacement u_1.

NOTE 3 It is evident that the presentation in terms of one-third-octave-band stiffness forms a practical reduction of the amount of data. However, phase information is lost.

The results are presented in terms of the level of frequency-band-averaged dynamic transfer stiffness in accordance with 3.18.

Geometric centre frequencies f_{m} for one-third-octave pass bands shall be used in agreement with ISO 266.

8.3 Presentation of one-third-octave-band results

The presentation of the dynamic transfer stiffness levels for one-third-octave bands may be in tables and/or in graphical form. A table shall contain centre frequencies of one-third-octave bands, levels of dynamic transfer stiffness in decibels, and a specification of the reference value (i.e. 1 N/m).

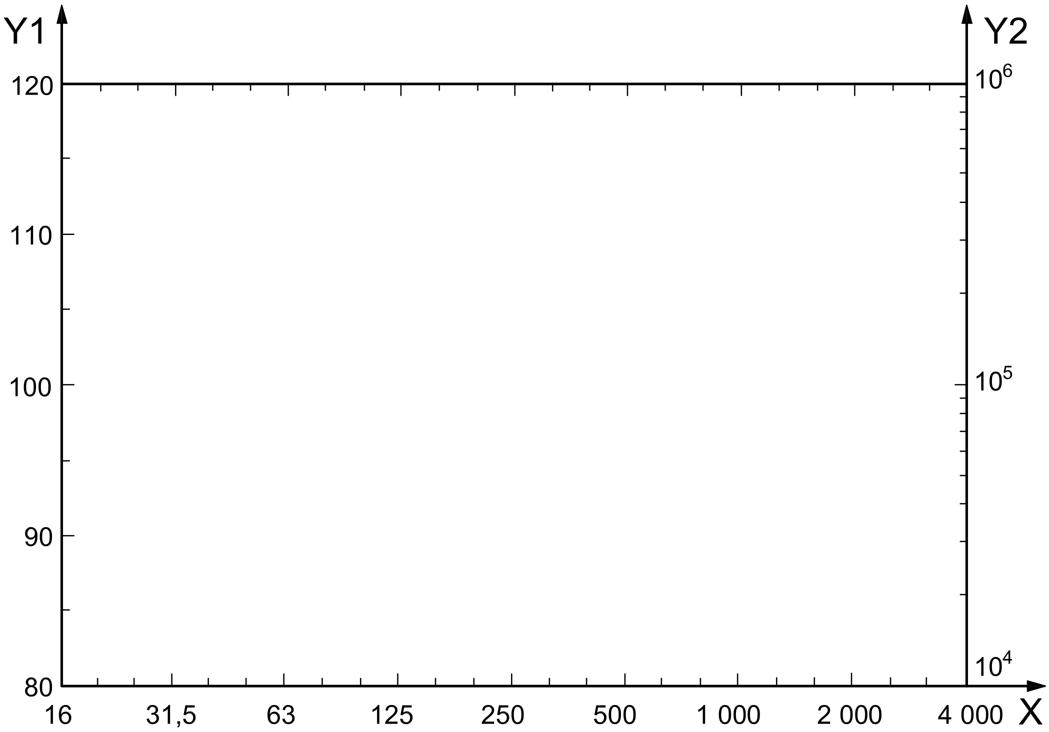
The format of the graphs shall be as follows:

- vertical scale: 20 mm for 10 dB or equivalently for a factor $10^{1/2}$ in magnitude;
- horizontal scale: 5 mm per one-third-octave band.

In print, these dimensions may be enlarged or reduced, as long as the proper ratio is maintained. Grids may be used for the sake of clarity.

NOTE An example of the graph format is shown in Figure 8. In addition to the decibel scale (vertical scale on the left), a logarithmic vertical scale, in newtons per metre, is given on the right.

The presentations shall include a clear description of the transfer stiffness concerned, i.e. for the normal direction or for which transverse direction. Moreover, the temperature, the static preload and any other relevant special test conditions shall be specified.



Key

F_{static} = ... N, T = ... °C

X	frequency, Hz
Y1	$L_{k_{\text{av}}}$, dB (ref. 1 N/m)
Y2	k_{av}, N/m

Figure 8 — Example of the graph for presenting one-third-octave-band levels of the dynamic transfer stiffness at specified test conditions with an example of scale values

8.4 Presentation of narrow-band data

Optionally, the magnitude and phase spectra of the dynamic transfer stiffness and spectra of the loss factor may be presented. The frequency resolution of the narrow-band analysis shall then be used.

The presentation of the level of magnitude of the dynamic stiffness shall be in graphical form and shall specify the reference value (i.e. 1 N/m). The format of the graphs should preferably be as follows:

- vertical scale: 20 mm for 10 dB or equivalently for a factor of magnitude $10^{1/2}$;
- horizontal scale: 15 mm per octave band.

The presentation of the phase data shall be in graphical form.

The format of the graphs should preferably be as follows:

- vertical scale: 40 mm for the range −180° to +180°;
- horizontal scale: 15 mm per octave band.

The presentation of the loss factor shall be in graphical form. The format of the graphs should preferably be as follows:

- vertical scale: 20 mm for a factor 10 in η;
- horizontal scale: 15 mm per octave band.

Linear scales for frequency and stiffness are allowed for narrow-band data in the frequency range 0 Hz up to 20 Hz.

NOTE See further remarks in 8.3 on printing

9 Information to be recorded

All relevant information shall be recorded, such as:

a) the name of the organization that performed the test;

b) information on the test element, including:

  - manufacturer, type, serial number;
  - description of the element; in cases where this is not self-evident, the test element and non-test elements (auxiliary parts not included in the tests) shall be clearly defined;
  - data provided by the manufacturer, in relation to the application as vibration attenuator;

c) photograph(s) or diagrams of resilient element and test arrangement; description of auxiliaries for static preload(s);

d) descriptions of excitation mass, if present (dimensions, material, mass) and of attachment to the test element;

e) spectra of acceleration level differences to check Inequality (1) and Inequality (3) (see 6.1 and 6.4);

f) frequency f_{UL} up to which inequalities (1), (2) and (3) hold (see 6.1, 6.2 and 6.4);

g) static preload(s), in newtons or pascals;

h) environmental temperature(s) and its variation during the tests, in degrees Celsius;

i) other test conditions, such as:

  - relative humidity, in percent;
  - pre-conditioning of the test element;
  - any other relevant special condition (e.g. static deflection and super-imposed low-frequency vibration: amplitude, frequency);

j) description of test signal(s);

k) spectrum of acceleration level L_{a1} at the input side of the test element (displacement levels, if displacements have been measured);

l) the measurement and analysis equipment used, including the type, location, serial number, calibration and manufacturer;

m) presentation of frequency-averaged dynamic transfer stiffness, in one-third-octave-band levels (up to f_{UL});

n) description of the linearity test (see 7.7), including data on levels or amplitude range of the acceleration a_1 or the displacement u_1 for which the test data are considered to be valid;

o) description of tests on the possible influence of background noise;

p) description of tests on the possible influence of flanking transmission (see 6.3);

q) tolerances for the environmental temperature or humidity within which the test values are considered valid, for resilient elements of which it is known or reasonable to expect that the dynamic stiffness is very sensitive to these environmental conditions.

The following are optional:

r) narrow-band magnitude spectra of dynamic transfer stiffness;

s) narrow-band phase spectra of dynamic transfer stiffness;

t) narrow-band spectra of loss factor, including a statement (with reference to ISO 10846-1) that η is only directly representative of the dissipation losses at low frequencies, where inertial forces inside the test element are negligible;

u) real and imaginary part of transfer stiffness;

v) simplified information of upper limit of input levels for which the test data are considered to be valid (e.g. a maximum of r.m.s. displacements);

w) static load-deflection curve (see Annex A)

10 Test report

The test report shall make reference to this part of ISO 10846 and shall include at least the items mentioned in Clause 9 under a), b), g), h), l) and m).

The test report shall include an evaluation of uncertainty; see 7.6.3.

Annex A
(informative)

Static load-deflection curve

If considered useful, the static load-deflection curve within the range 0 % to 100 % of the maximum permissible load may be added to the test report, with a description of or a reference to the measurement procedure. See, for example, References [6] and [7].

Annex B
(informative)

Measurement uncertainty

B.1 General

The uncertainty of the dynamic transfer stiffness measured according to this part of ISO 10846 has several origins, each of which leads to a partial contribution to the total uncertainty. Some of the partial contributions are well predictable, whereas others are rather unpredictable, in particular, for occasional users of this part of ISO 10846.

The dynamic transfer stiffness is determined from a ratio between input acceleration (or velocity, or displacement) and output blocking force, and may be defined as a frequency response function of which the uncertainty may be frequency dependent.

Well-known uncertainty contributions for measuring a frequency response function originate from the measurement instrumentation, notably the accelerometers, force transducers, signal analysers and signal processing parameters. These contributions can be controlled very well, because for the measured quantities and the frequency range of interest, high quality and well-understood transducers and signal analysers are available. Moreover, extensive knowledge has been published on transducer and analyser calibrations and on the relevant signal processing.

Uncertainty contributions, which are insufficiently known or difficult to control, are those connected with the variety of laboratory test rigs, which is permitted, and with the large variety of resilient elements, which may be tested according to this part of ISO 10846. Because systematic studies and inter-laboratory comparisons on these latter sources of uncertainty are lacking, the information on them is very scarce. However, generally speaking, these uncertainty contributions will vary depending on the combination of the test element and laboratory test rig. Therefore, for many intended users of this part of ISO 10846, it will not be possible to determine an accurate value of the uncertainty contributions involved. Especially for very stiff and (or) big test elements, these uncertainty contributions can become much bigger than those due to transducers, analysers and signal processing.

Because in this part of ISO 10846 several requirements are made to limit specified uncertainty contributions, a useful estimation of the various uncertainty contributions is still considered to be possible. In the following clauses of this Annex the sources of uncertainty are discussed one by one, and a structure is presented for the evaluation of the partial uncertainty contributions and the resulting total uncertainty.

B.2 Level of frequency-averaged dynamic transfer stiffness

The general expression for the calculation of the level of frequency-averaged dynamic transfer stiffness for one-third-octave bands, $L_{k_{\text{av}}}$, is given by the following equation:

$$L_{k_{\text{av}}} = \widehat{L}_{k_{\text{av}}} + \delta_{\text{ins}} + \delta_{\text{rep}} + \delta_{\text{rig}} + \delta_{\text{lin}} \quad \text{(B.1)}$$

where

$\widehat{L}_{k_{\text{av}}}$ is the input quantity determined according to 3.18 from the one-third-octave band value of the measured frequency-averaged dynamic transfer stiffness (see 8.2);

δ_{ins} is an input quantity to allow for any uncertainty contribution due to the calibration and use of accelerometers, force transducers (load cells) and analyser, and due to the signal processing;

δ_{rep} is an input quantity to allow for any uncertainty contribution due to the installation repeatability of the test element in a particular laboratory test rig;

δ_{rig} is an input quantity to allow for any uncertainty contribution originating from laboratory test rig properties;

δ_{lin} is an input quantity to allow for any uncertainty contribution due to approximate, instead of perfect, linear behaviour of the test element as observed in the test for linearity (see 7.7).

NOTE The input quantities included in Equation (B.1), to allow for uncertainty contributions, are those thought to be applicable in the state of knowledge at the time when this part of ISO 10846 was being prepared. However, further research could reveal that there are others.

The partial contributions to the combined uncertainty of the dynamic transfer stiffness level, associated with each of the input quantities, are briefly analysed in B.3 and B.4.

B.3 Standard uncertainties

B.3.1 Signal processing and background noise

By obeying the requirements for signal averaging (see 7.5) and for signal-to-noise ratios (see 7.6.1), the standard uncertainty $u_{\hat{L}}$ will not exceed 0,3 dB. Therefore, the user of this part of ISO 10846 is encouraged to use this value, when calculating the combined uncertainty. The uncertainty contribution due to signal processing and background noise is assumed to be a normally distributed random variable.

B.3.2 Instrumentation

The uncertainty due to measurement instrumentation will be caused by systematic and random effects.

Random effects may originate from transducer calibrations. Systematic effects may originate from frequency-dependent variations in transducer frequency responses (see 6.5 to 6.7), from uncertainties in analyser channel gains (see 6.8) and from the positioning of accelerometers (see 7.3).

The total uncertainty contribution due to the measurement instrumentation is assumed to be a normally distributed random variable with a mean value of 0 dB and a standard uncertainty. Experience has shown that, with good choices and precautions, the standard uncertainty u_{ins} will not exceed 0,3 dB. However, when just the minimum instrumentation requirements of this part of ISO 10846 are met, i. e. when no extra efforts are made for using frequency response calibrations of transducers and analysers, a better estimate for the standard uncertainty u_{ins} is 0,5 dB. Therefore, the user of this part of ISO 10846 is encouraged to report either a reasoned estimate of standard uncertainty u_{ins} or to postulate that u_{ins} = 0,5 dB.

Table B.1 — Uncertainty budget for determination of the level of frequency-averaged dynamic transfer stiffness

Quantity	**Estimate** dB	**Standard uncertainty** u_i dB	**Probability distribution**	**Sensitivity coefficient** c_i	**Uncertainty contribution** $c_i u_i$ dB
Level of measured frequency-averaged dynamic transfer stiffness	$\hat{L}_{k_{\text{av}}}$	0,3	normal	1	0,3
δ_{ins}	0	0,5	normal	1	0,5
δ_{rep}	0	$p/\sqrt{3}$ [a]	rectangular	1	$p/\sqrt{3}$
δ_{rig}	0	0,5	rectangular	1	0,5
δ_{lin}	0	0,5	rectangular	1	0,5

[a] $2p$ is the difference between measured maximum and minimum level in repeatability tests.

B.3.3 Installation of the test element

The uncertainty due to the installation of a test element in a particular laboratory test rig originates from the finite dynamic stiffness of connections between the test element and the test rig or its auxiliaries. Especially, for big test elements or for big auxiliaries, such as force distribution plates, a good quality of the connections may become critical to avoid large connection stiffness uncertainties, which may lead to measurement uncertainties; see 7.1.

In principle, the standard uncertainty u_{rep} can be determined by performing a series of tests for installation repeatability. However, because of the required large effort, this will usually be uneconomic. For this reason, no general test procedures have been prescribed in this part of ISO 10846 for determining this type of uncertainty. Nevertheless, a test laboratory may describe its own repeatability tests or other procedure for making an estimation of the standard uncertainty and the appropriate probability distribution.

If such an effort cannot be made, users of this part of ISO 10846 are encouraged to report at least their experience-based estimation of the maximum deviation in dB. The latter can be done on the basis of a limited set of repeatability measurements. By the difference between the maximum and minimum measured values of the frequency-averaged dynamic transfer stiffness level equal to $2p$ dB then, without having specific knowledge of the probability distribution, the standard uncertainty due to installation repeatability may be taken as $u_{\text{rep}} = p/\sqrt{3}$ dB .

B.3.4 Laboratory test rig

The uncertainty due to the properties of the laboratory test rig is predominantly determined by the discrepancy of the measured output force and the blocking output force. A primary cause is the violation of the requirement for zero vibration on the output side of the test element, because in actual tests always $a_2 \neq 0$. Obeying Inequalities (1) and (2), as specified in this part of ISO 10846, is supposed to limit the maximum deviation in the blocking output force level due to apparatus properties within 1,5 dB.

For quantifying the contribution of the test-rig-related uncertainty to the total uncertainty, users of this part of ISO 10846 are, generally speaking, advised to assume a rectangular probability distribution and a standard uncertainty $u_{\text{rig}} = 1{,}5/2\sqrt{3} \approx 0{,}5$ dB . However, it appears that, in certain cases, this uncertainty contribution can be diminished by using special analysis procedures, such as described in [8]. Therefore, in cases where a better estimation of u_{rig} is available, the user is encouraged to use that value.

B.3.5 Test for linearity

The uncertainty contribution due to approximate, instead of perfect, linear behaviour of the test element, is kept between known limits, due to the restrictions for valid measurement results as defined by the test of linearity. According to 7.7, for valid measurements, a good estimation of the maximum errors in transfer stiffness levels due to non-linear behaviour is 1,5 dB.

For quantifying the contribution of linearity related uncertainty to the total uncertainty, users of this part of ISO 10846 are advised to assume a rectangular probability distribution and a standard uncertainty $u_{\text{lin}} = 1{,}5/2\sqrt{3} \approx 0{,}5$ dB .

B.4 Contributions to combined measurement uncertainty

The contributions to the combined uncertainty depend on each of the input quantities in Equation (B.1), their respective probability distributions and sensitivity coefficients c_i. The uncertainty budget needed for the calculation of the combined uncertainty is given in Table B.1.

B.5 Calculation of expanded uncertainty for a coverage probability of 95 %

The combined standard uncertainty of the frequency-averaged dynamic transfer stiffness level $u\left(L_{k_{\text{av}}}\right)$ is given by the following equation

$$u(L_{k_{\text{av}}}) = \sqrt{\sum_{i=1}^{5} \left(c_i u_i\right)^2} \tag{B.2}$$

The expanded uncertainty U is defined for a coverage probability of 95 %, meaning that the interval

$\left[\widehat{L}_{k_{\text{av}}} - U, \widehat{L}_{k_{\text{av}}} + U\right]$ covers 95 % of the values of $L_{k_{\text{av}}}$ that might reasonably be attributed to $L_{k_{\text{av}}}$.

Because the combination of the five inputs are assumed to result in a normal distribution, the value of the expanded uncertainty is given by

$$U = 2u(L_{k_{\text{av}}}) \tag{B.3}$$

NOTE Because values of some of the standard uncertainties may be frequency dependent, the calculation according to Equation (B.3) might be performed for each frequency band for which such input data are known.

Bibliography

[1] ISO 1683, *Acoustics — Preferred reference quantities for acoustical levels*

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[3] ISO 7626-2, *Vibration and shock — Experimental determination of mechanical mobility — Part 2: Measurements using single-point translation excitation with an attached vibration exciter*

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[6] DIN 2096-1, *Zylindrische Schraubendruckfedern aus runden Drähten und Stäben — Güteanforderungen bei warmgeformten Druckfedern* (*Helical compression springs made of round wire and rod — Quality requirements for hot formed compression springs*)

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