INTERNATIONAL STANDARD

ISO 18437-1

First edition
2012-08-15

Mechanical vibration and shock — Characterization of the dynamic mechanical properties of visco-elastic materials —

Part 1: Principles and guidelines

Vibrations et chocs mécaniques — Caractérisation des propriétés mécaniques dynamiques des matériaux visco-élastiques —

Partie 1: Principes et lignes directrices

Reference number
ISO 18437-1:2012(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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 18437-1 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*.

ISO 18437 consists of the following parts, under the general title *Mechanical vibration and shock — Characterization of the dynamic mechanical properties of visco-elastic materials*:

— *Part 1: Principles and guidelines*

— *Part 2: Resonance method*

— *Part 3: Cantilever shear beam method*

— *Part 4: Dynamic stiffness method*

— *Part 5: Poisson ratio based on comparison between measurements and finite element analysis*

Introduction

Visco-elastic materials are used extensively to reduce vibration amplitudes in structural systems through dissipation of energy (damping) or isolation of components, and in acoustical applications that require a modification of the reflection, transmission or absorption of energy. Such systems often require specific dynamic mechanical properties in order to function in an optimum manner. Energy dissipation is due to interactions on the molecular scale and can be measured in terms of the lag between stress and strain in the material. The visco-elastic properties, modulus, and loss factor of most materials depend on frequency, temperature, strain amplitude, and pre-strain. In addition to modulus and loss factor, sometimes Poisson ratio is an important property required for predictions. The choice of a specific material for a given application determines the system performance. The goal of this International Standard is to provide brief descriptions of the three methods for elastic modulus and loss factor and two methods for Poisson ratio, the details of construction of each apparatus, measurement range, and the limitations of each apparatus. This International Standard applies to the linear behaviour observed at small strain amplitudes.

Mechanical vibration and shock — Characterization of the dynamic mechanical properties of visco-elastic materials —

Part 1: Principles and guidelines

1 Scope

This part of ISO 18437 establishes the principles underlying ISO 18437-2 to ISO 18437-5 for the determination of the dynamic mechanical properties (i.e. elastic modulus, shear modulus, bulk modulus, loss factor, and Poisson ratio) of isotropic visco-elastic resilient materials used in vibration isolators from laboratory measurements. It also provides assistance in the selection of the appropriate part of this International Standard.

This part of ISO 18437 is applicable to isotropic resilient materials that are used in vibration isolators in order to reduce:

a) the transmissions of audio frequency vibrations to a structure that can, for example, radiate fluid-borne sound (airborne, structure-borne or other);

b) the transmission of low frequency vibrations which can, for example, act upon humans or cause damage to structures or sensitive equipment when the vibration is too severe;

c) the transmission of shock and noise.

The data obtained with the measurement methods that are outlined in this part of ISO 18437 and further specified in ISO 18437-2 to ISO 18437-5 can be used for:

1) the design of efficient vibration isolators;

2) the selection of an optimum resilient material for a given design;

3) the theoretical computation of the transfer of vibrations through vibration isolators;

4) information during product development;

5) product information provided by manufacturers and suppliers;

6) quality control.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 472, *Plastics — Vocabulary*

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

ISO 4664-1, *Rubber, vulcanized or thermoplastic — Determination of dynamic properties — Part 1: General guidance*

ISO 6721-1, *Plastics — Determination of dynamic mechanical properties — Part 1: General principles*

ISO 10846-2, *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*

ISO 23529, *Rubber — General procedures for preparing and conditioning test pieces for physical test methods*

3 Terms and definitions

For the purposes of this part of ISO 18437, the terms and definitions given in ISO 472, ISO 2041, ISO 4664-1, ISO 6721-1, ISO 10846-2, ISO 23529 and the following apply.

3.1
Young modulus
modulus of elasticity
E
ratio of the normal stress to linear strain

[SOURCE: ISO 80000-4:2006,[2] 4.1, modified.]

Note 1 to entry: The Young modulus is expressed in pascals.

Note 2 to entry: The complex Young modulus, E^*, for a visco-elastic material is represented by $E^* = E' + \mathrm{i}E''$, where E' is the real (elastic) component of the Young modulus and E'' is the imaginary (loss modulus) component of the Young modulus. The real component represents elastically stored mechanical energy, while the imaginary component is a measure of mechanical energy loss.

3.2
loss factor
ratio of the imaginary component to the real component of a complex modulus

Note 1 to entry: When a material shows a phase difference or loss angle, δ, between dynamic stress and strain in harmonic deformations, the loss factor is equal to tan δ.

3.3
linearity
property of the dynamic behaviour of a resilient material if it satisfies the principle of superposition

Note 1 to entry: The principle of superposition is 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 holds for all values of α, β and $x_1(t)$, $x_2(t)$; α and β are arbitrary constants.

Note 2 to entry: In practice the above test for linearity is impractical. Measuring the dynamic modulus for a range of input levels can provide a limited check of linearity. For a specific preload, if the dynamic transfer modulus is nominally invariant, the system measurement is considered linear. In effect this procedure checks for a proportional relationship between the response and the excitation.

4 Measurement principles

4.1 General

The Young modulus of a visco-elastic material is dependent on frequency and temperature. Theoretical details of the various modes of vibration, types of moduli and commonly used test arrangements are well known, are adequately covered in ISO 6721-1 and ISO 4664-1, and are not repeated here. ISO 18437-2 to ISO 18437-4 specify three additional methods that 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 this part of ISO 18437. In addition, ISO 18437-4 can include the application of static preload. Finally, ISO 18437-5 specifies a method for determining the Poisson ratio of a material by comparing measurements with finite element calculations. The four methods described here are limited to the measurement of the linear behaviour of materials observed at small strain amplitudes.

The conditions for the validity of the measurement methods are:

a) linearity of the vibrational behaviour of the isolator;

NOTE The term isolator includes elastic elements with non-linear static load deflection characteristics as long as the elements show approximate linearity for vibration behaviour for a given static preload.

b) equal distribution of the interfaces of the vibration isolator with the adjacent source and receiver structures;

c) no interaction between the vibration isolator and the surrounding fluid (usually air) medium.

It is possible that condition c) is not fulfilled for vibration isolators made up from an open-cell poro-elastic material, e.g. foam. For frequencies typically greater than 100 Hz, the interaction of the fluid and solid phases of the material can be great enough to modify its rigidity and loss.

4.2 Resonance method

4.2.1 Introduction

In the resonance method, the transmissibility (of displacement, velocity or acceleration) of a specimen is measured with the input side driven by a vibration source and the output loaded by a mass. The magnitude and phase information, mass specimen density and length provide the data required to determine the complex Young modulus. Figure 1 shows the principle of the method.

4.2.2 Test equipment

The following test equipment is required:

a) electro-dynamic driver;

b) accelerometers;

c) amplifiers;

d) test stand;

e) environmental chamber;

f) dual-channel spectrum analyser;

g) computer.

4.2.3 Test specimen preparation and mounting

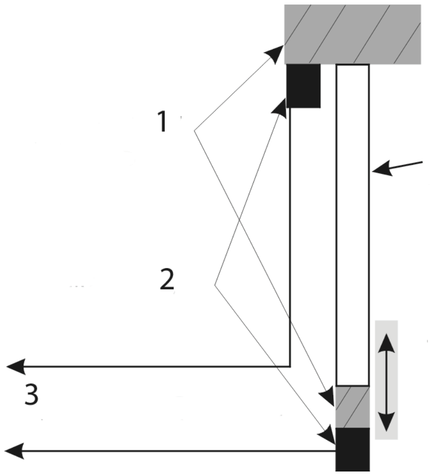
Test specimens are moulded into the shape of a bar that is typically 100 mm long with cross-sectional dimensions of 6 mm to 7 mm. The specimen cross-section may be square or circular. The length, density and mass of the specimen shall be determined before the specimen is mounted. The specimen is bonded between the mounting blocks, and accelerometers are also bonded as shown in Figure 1. A rigid adhesive such as epoxy or cyanoacrylate is acceptable. The finished assembly is rigidly mounted to the driver so as to produce pure extensional waves in the specimen.

4.2.4 Data acquisition

Typically the driver is excited with a random signal; the two-channel spectrum analyser acquires the data and performs a fast Fourier transform (FFT) analysis and averaging. This contains information concerning the mass spring response of the assembly and wave effects in the test specimen. The mass of the mounting block and specimen length shall be chosen so that the lowest frequency resonance is that of the mass spring system. The lowest frequency resonance shall be clearly separated from the higher frequency wave effects. A typical frequency range is 100 Hz to 5 000 Hz.

4.2.5 Analysis of results

The real and imaginary parts of the complex Young modulus are determined from the length, mass, and density of the specimen and from parameters obtained from solutions to the wave equation consisting of two coupled transcendental equations. The solution is obtained by numerical computation using the Newton–Raphson method at the experimentally determined resonant parameters (i.e. amplitude of the transfer function, frequency and mode number). Details are given in ISO 18437-2.



Key

1 mounting blocks

2 accelerometers

3 accelerometer outputs

4 test specimen

5 direction of vibration

Figure 1 — Principle of the resonance method

4.3 Cantilever shear beam method

4.3.1 Introduction

In the cantilever shear beam method, a specimen is rigidly mounted at one end and the free end is driven so as to bend or flex the specimen. In order to ensure a specific mode of bending, specific mounting requirements need to be met and these are specified in ISO 18437-3. The measurement of the complex force necessary to displace the specimen and the resulting complex displacement provides the data required to compute a complex Young modulus. Figure 2 shows the principle of the measurement.

4.3.2 Test equipment

The following test equipment is required:

a) electro-dynamic driver;

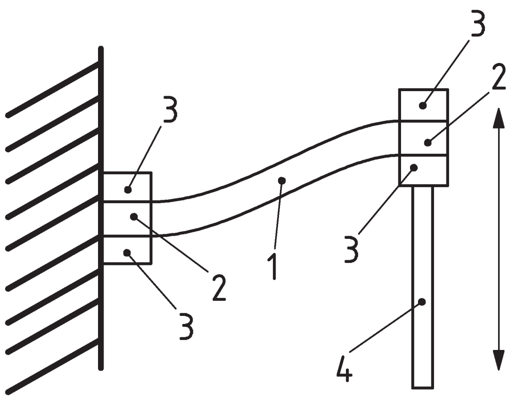
b) force sensor;

c) displacement sensor;

d) clamping system;

e) environmental chamber;

f) computer.



Key

1 beam specimen

2 specimen end blocks

3 specimen clamps

4 drive shaft

Figure 2 — Schematic diagram of the cantilever shear beam method

4.3.3 Test specimen preparation and mounting

Test specimens are typically cut from a sheet moulded or cast to the desired thickness using a small band saw or razor. It has been found that machining specimens from a thicker sample often affects the properties of the material. A typical specimen has length, $l = (12 \pm 0,5)$ mm by width, $b = (10 \pm 0,5)$ mm by height, $h = (3 \pm 0,25)$ mm. Steel or aluminium end blocks are attached to the ends of the specimen for clamping purposes. The dimensions of the end block are typically $l = (6,4 \pm 0,2)$ mm by $b = (11,0 \pm 0,2)$ mm by $h = (4,0 \pm 0,2)$ mm. The specimen is bonded to the end blocks using a rigid adhesive such as epoxy, urethane or cyanoacrylate. The specimen is mounted in a clamping fixture so as to produce the deformation shown in Figure 2.

4.3.4 Data acquisition

First, determine the complex stiffness of the system suspension by making measurements with no specimen in place. Measurements are made both with and without an end block (which serves as an added mass) at low and high frequencies, typically 1 Hz and 30 Hz. Once the stiffness of the instrument has been determined, measurements are made on the specimen mounted as shown in Figure 2. Force is applied to the specimen at the discrete frequencies, typically 0,3 Hz to 30 Hz, and temperatures selected for the evaluation. Typically the maximum displacement is limited to 64 µm.

4.3.5 Analysis of results

The basic principle of operation of the cantilever shear beam apparatus is to determine the force needed to induce a measurable displacement of the specimen. As the magnitude of the displacement depends on the modulus of the specimen, this value may be calculated by relating force to displacement with an equation which involves such factors as the system stiffness and viscous damping coefficient, vibrating mass, specimen geometry, and Poisson ratio. The solution of the dynamic equation yields the elastic Young modulus and loss factor. Details are given in ISO 18437-3.

4.4 Dynamic stiffness method

4.4.1 Introduction

The dynamic stiffness of the specimen is determined by measuring the input force on one side of the specimen while the displacement, velocity or acceleration is measured on the same or other side of the specimen, depending on the setup. The amplitude and phase relationship between the two measured quantities and the specimen geometry provide the data required to compute the complex modulus. Using different experimental test configurations, it is possible to measure the three different moduli, Young (E), shear (G), and bulk (K), which characterize a material. In some cases, the material is placed in the test fixture where it is subjected to a static preload strain with the help of a force actuator. Figure 3 illustrates the principle wherein, using appropriate force and strain gauges, the dynamic acting force and resulting strain are measured in the dynamic stiffness method for determining the three different moduli.

4.4.2 Test equipment

The following test equipment is required:

a) electro-dynamic driver;

b) accelerometer or displacement sensor;

c) amplifiers;

d) test stand;

e) environmental chamber;

f) dual-channel spectrum analyser;

g) computer.

4.4.3 Test specimen preparation and mounting

Test specimens are moulded into the shapes appropriate for each of the test conditions. The specimen cross-section may actually be square or circular. The dimensions, density and mass of the specimen shall be determined before the specimen is mounted. The specimen may be bonded to test plates to ensure proper deformation. A rigid adhesive such as epoxy or cyanoacrylate is acceptable. The test specimen shall have dimensions such that it is completely visco-elastic in character over the total frequency range of interest. This is based on the assumption that the test specimen is considered to be massless; i.e. all wave effects shall be three to five times larger than the upper frequency limit of measurement.

4.4.4 Data acquisition

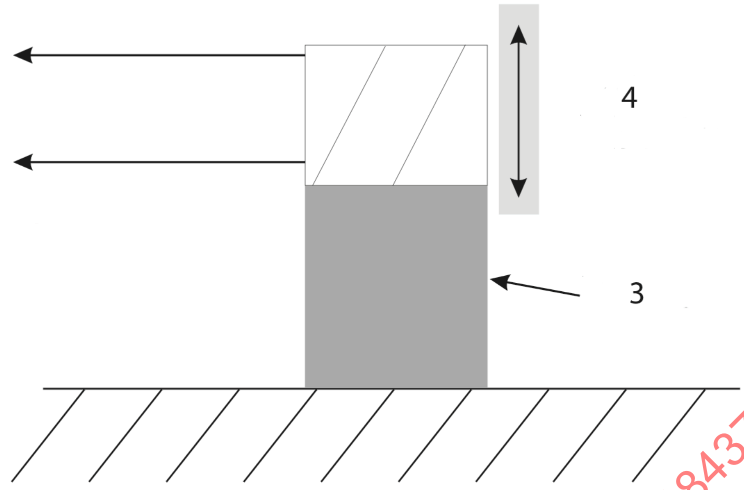
The force gauge typically is driven with random noise and the strain sensor records the specimen response; the two-channel spectrum analyser acquires this data and performs an FFT analysis and averaging. In each case the equipment shall be calibrated to determine the dynamic stiffness of the test device itself and this is factored into the analysis.

4.4.5 Analysis of results

When performing the measurement using the specific conditions mentioned above, the general expression for the determination of the complex elastic modulus has the form

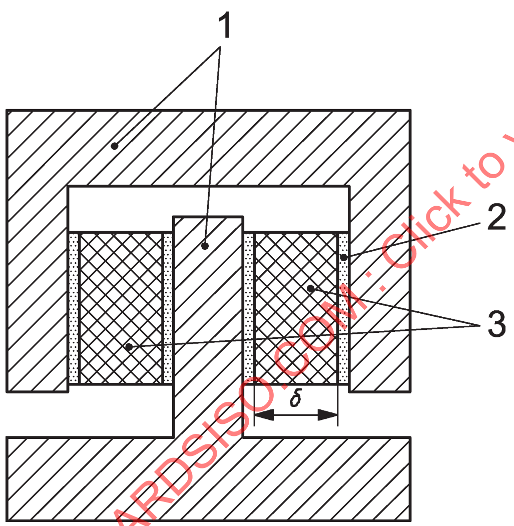
$$E^*(f), G^*(f), K^*(f) = \alpha_{E,G,K} \frac{F(f)}{\delta(f)} \quad (1)$$

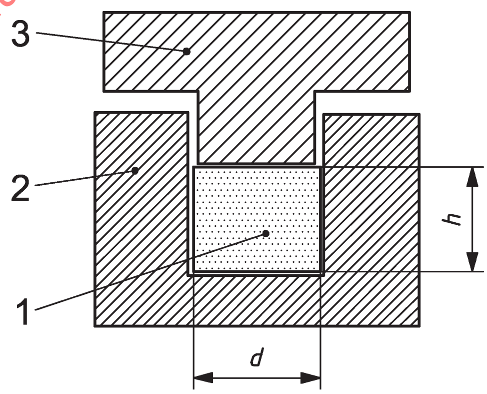
In Formula (1), $\alpha_{E,G,K}$ is the ratio of the measured modulus of the tested material to the stiffness of the test specimen under the appropriate strain (longitudinal, shearing, and bulk). The value of the ratio $\alpha_{E,G,K}$ depends on the test configuration and specimen geometry, whereas $F(f)/\delta(f)$ is the complex valued frequency ratio of the output force to the actuator displacement. Specific details are given in ISO 18437-4.



Key
1 force output
2 acceleration output
3 test specimen
4 direction of vibration

a) Young modulus





Key
1 covering straps
2 plate
3 test specimens
δ thickness

b) shear modulus

Key
1 test specimen
2 housing
3 piston
d diameter
h height

c) bulk modulus

Figure 3 — Schematic diagrams of dynamic stiffness methods

4.5 Estimation of the Poisson ratio

4.5.1 Introduction

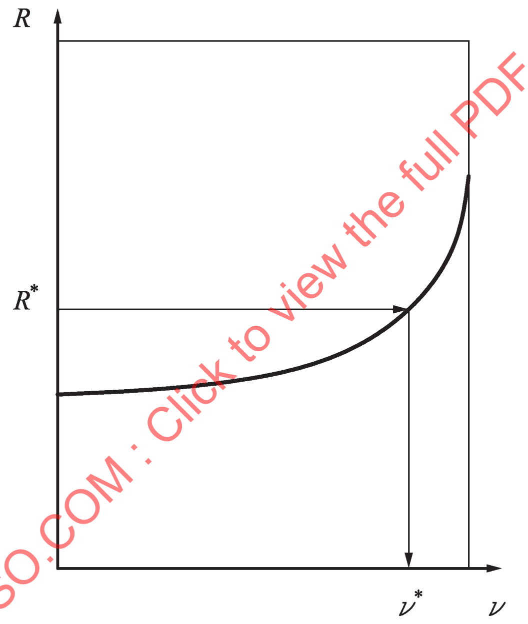
While accurate elastic modulus and loss factor data suffice for the analysis of many acoustic or vibration problems, accurate values for the Poisson ratio are often required when undertaking finite element numerical analysis. Since in practice most numerical predictions are done for components of complicated geometric shape, the goal of this method is to determine the Poisson ratio by comparing measurements of force-deflection with numerical predictions as functions of the Poisson ratio for specimens of simple geometry.

4.5.2 Measurement principles

ISO 18437-5 uses a quasi-static method based on the principle that measurements of compressional stiffness are the same as those obtained from axisymmetrical finite element calculations on a disk-shaped specimen as functions of the Poisson ratio and/or elastic modulus. The measurements and predictions account for the fact that the disk specimen bulges sideways when compressed between two rigid plates to which it is bonded. Depending on whether the Poisson ratio alone or in combination with the elastic modulus is to be determined, the single or double specimen measurement method may be used, as appropriate.

4.5.3 Single specimen measurement method

The key idea and practice of this method is simply to prepare a chart of dimensionless stiffness versus the Poisson ratio for a disk-shaped specimen with a large shape factor by finite element method (FEM) computations, to measure the stiffness by the excitation test, and to select a value of the Poisson ratio from the chart corresponding to the measured stiffness as shown in Figure 4.



Key

R stiffness/dimensionless

ν Poisson ratio

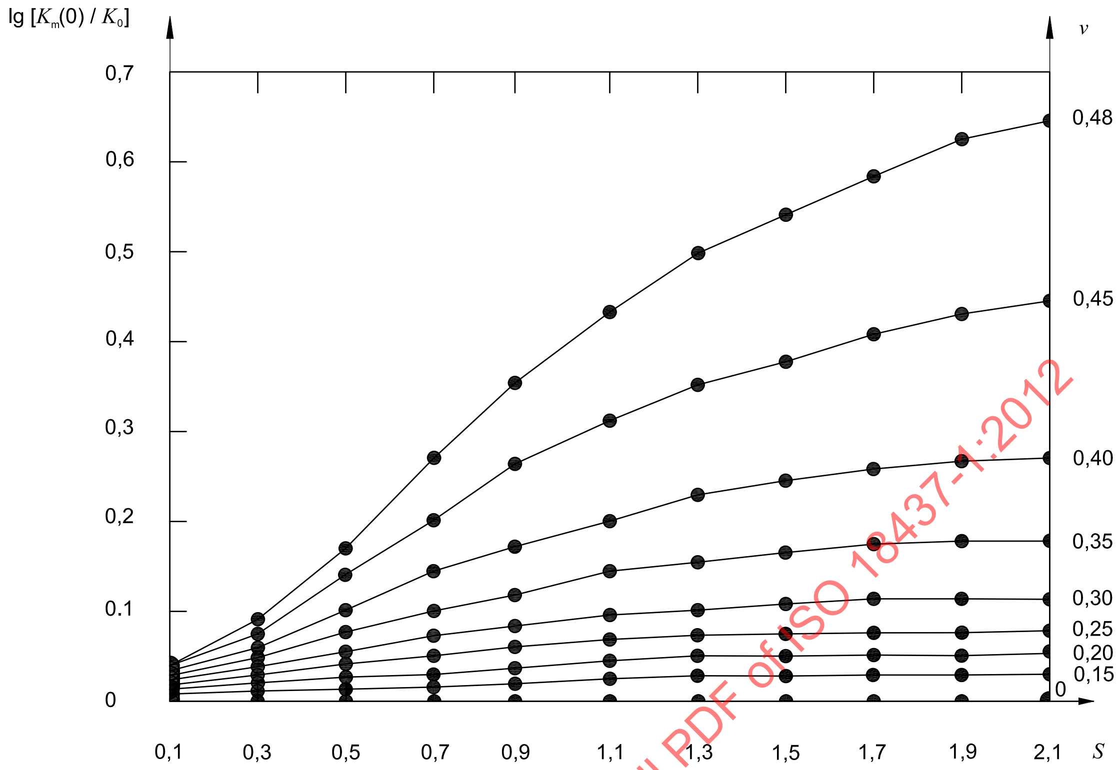
R^* measured stiffness

ν^* Poisson ratio corresponding to R^*

Figure 4 — Plot of stiffness as a function of the Poisson ratio $R(\nu)$ by FEM computations

4.5.4 Double specimen measurement method

This method uses the fact that the ratio of the apparent Young modulus to the true Young modulus is equal to the ratio of stiffness for disk-shaped specimens to that of a long cylinder. The ratio can be formulated as a polynomial function of either the Poisson ratio or the shape factor with coefficients dependent on the other. An example of an FEM result is shown in Figure 5. As long as values of this ratio are available from experiments for two specimens of the same material, with identical Young modulus and Poisson ratio but different shape factors, equating the two polynomial expressions yields the Poisson ratio. The Young modulus can then be obtained by dividing the apparent Young modulus by the value of the polynomial expression. Specific details are given in ISO 18437-5.



Key

lg[$K_m(0)/K_0$]	normalized static compression stiffness
S	shape factor
v	Poisson ratio

Figure 5 — An example of variations of the normalized static compression stiffness as a function of the shape factor and the Poisson ratio from FEM computation

5 Time–temperature superposition

In general measurements over a limited frequency range, measurement may be extended through the application of the time–temperature superposition method. See ISO 18437-2 and ISO 18437-3.

6 Specimen conditioning

Test specimens shall be adequately aged after moulding or vulcanization. The test specimens are thermally conditioned at each test temperature. In addition, materials are often sensitive to humidity. ISO 23529 shall be used for determining the temperatures, humidity and times for conditioning and testing.

7 Selection of appropriate method

Table 1 provides some guidance for the selection of the appropriate method from ISO 18437-2 to ISO 18437-4.

The Poisson ratio can be determined by the dynamic stiffness method either by measuring the bulk modulus and either the shear or Young modulus or by using the dynamic stiffness FEM method specified in ISO 18437-5. The choice of method largely depends on the stiffness of the material and the uncertainties in the measurement.

Table 1 — Guidance for selection

	Resonance method	Cantilever shear beam method	Dynamic stiffness method
Frequency range, Hz	100 to 5 000	0,01 to 50	1 to 10 000
Mode of deformation	extensional	flexural	Young, shear and bulk
Typical specimen size, m^3	0,006 × 0,006 × 0,1	0,003 × 0,01 × 0,012	varies with test equipment and value of modulus
Material type	rubber, plastic, polyurethane	rubber, plastic, polyurethane	rubber, plastic, polyurethane
Young modulus range, MPa	0,1 to 1 000	0,1 to 1 000	0,1 to 20 000
Loss factor range	0,01 to 2	0,01 to 2	0,01 to 2
Sensitivity to creep	low	very low	low
Preload	limited	no	some modes
NOTE The frequency range of measurement can be extended through the use of the time–temperature superposition principle.			

Annex A
(informative)

Linearity of resilient materials

In principle, the dynamic properties of a vibro-acoustic isolator are dependent on static preload, vibration amplitude, frequency, and temperature.

The assumption of linearity implies that the principle of superposition holds and that the dynamic stiffness at a given frequency is independent of amplitude. For many vibration isolators, this assumption is approximately satisfied when, under the appropriate static preload, the dynamic deformation amplitudes are small compared with the static deformation. However, it should be noted that this depends on the materials of which the vibration isolators are composed and a simple check should be carried out by comparing the dynamic stiffness characteristics for a range of input levels. If these are nominally invariant, then linearity can be assumed to hold.

For butyl rubber (IIR), Reference [3] presents data for the in-phase component and the phase angle of the dynamic shear modulus as a function of strain amplitude and of the percentage of carbon black. For strain amplitudes smaller than about 10^{-3}, the in-phase component and phase angle are hardly dependent on the vibration amplitude. However, a significant decrease of dynamic stiffness is seen when strain amplitudes exceed about 2×10^{-3}, especially for rubber with a high percentage mass fraction of carbon black.

Therefore, it is important to consider strain amplitudes that occur in practice and to check whether the test conditions are appropriate for the testing of rubber vibration isolators. For strain amplitudes smaller than about 10^{-3}, the assumption of linearity (implying, for example, amplitude-independent stiffness and reciprocity) seems justified.

Hydraulic mounts are increasingly used, especially for automotive applications. This type of vibration isolator may also show a very non-linear behaviour, i.e. stiffness strongly dependent on vibration amplitude. Because of their twofold purpose, i.e. damping of low-frequency engine vibration caused by road excitation and isolation of engine-generated structure-borne sound at higher frequencies, appropriate test amplitudes have to be applied for the whole frequency range of interest.

It is sometimes known a priori that linearity does not hold. In such cases, it can still be advantageous to apply many of the procedures described in ISO 10846.[1] Often this implies that, in addition, special test requirements need to be formulated with respect to preloads, signal amplitudes and measuring quantities.

Annex B
(informative)

Analysis of other ISO documents on dynamic testing

B.1 Review of documents

B.1.1 Introduction

There are a number of ISO documents for determining the dynamic mechanical properties of specimens subject to various end conditions under sinusoidal deformations. A specimen of known geometry is placed in an apparatus whose purpose to ensure a particular mode of oscillation. The mode of motion, the specific end conditions and the type of oscillation determine the specific equations required for determining the elastic modulus. The experimental apparatus typically consists of a set of clamps or bonding blocks, a device for applying the required vibrating strain at one end of the specimen, a device for determining the response of the specimen in most cases at the opposite end (stress or strain) and a temperature-controlled environment. The specimen shape varies considerably from method to method, thus all methods are not suitable for every situation. Some methods employ clamps to grip the specimens and are more subject to clamping inaccuracy and operator differences. Certain methods do not deform the specimen in an elementary mode and thus the calculation often requires corrections for bending, shear strain, and rotational effects. Finally, the mode of oscillation may be forced, resonant or freely decaying. The following is a brief summary of the methods for which ISO documents are available from the rubber and plastics testing perspective.

B.1.2 TC 45/SC 2 Testing and analyses

B.1.2.1 ISO 4664-1, *Rubber, vulcanized or thermoplastic — Determination of dynamic properties — Part 1: General guidance*

Guidance is provided in using the two types of motion, free and forced, and the general equations of motion. Various modes of deformation are described. A good general summary of the procedure is provided.

B.1.2.2 ISO 4664-2, *Rubber, vulcanized or thermoplastic — Determination of dynamic properties — Part 2: Torsion pendulum methods at low frequencies*

In this method, a long strip of material of uniform cross-section is fixed at one end and the free end with added mass is set into a twisting torsion motion and allowed to decay freely. The period of vibration and its decay determine the shear modulus. The test is primarily used to determine the rubbery transition region by making measurements over a wide temperature range. The test frequency is low, typically from 0,1 Hz to 10 Hz, and varies with temperature. ISO 4664-2 is similar to ISO 6721-2 (B.1.3.5) for plastics.

B.1.3 TC 61/SC 2 Mechanical properties

B.1.3.1 ISO 458-1, *Plastics — Determination of stiffness in torsion of flexible materials — Part 1: General method*

This is a general method for the determination of the stiffness in torsion at various temperatures, particularly below 0 °C. An observation of torque and angle of deflection is made after an arbitrarily fixed time of load application, using a specified testing apparatus.

B.1.3.2 ISO 458-2, *Plastics — Determination of stiffness in torsion of flexible materials — Part 2: Application to plasticized compounds of homopolymers and copolymers of vinyl chloride*

This is a special case of the general method with an angle of deflection between 55° and 65° and for three values of the torsion stiffness: 300 MPa, 23 MPa and 4 MPa.

B.1.3.3 ISO/TR 4137, *Plastics — Determination of modulus of elasticity by alternating flexure*

The Young modulus is determined using a Savarts pendulum. The method is applicable to products for which the characteristic determined is greater than 1 500 MPa and for which it is possible to prepare specimens from 1 mm to 5 mm in thickness by cutting. The elasticity of the test piece is employed for the transmission of energy from one pendulum to another, the test piece being used as a support for both pendulums. The amplitude of the oscillations of the driving pendulum gradually decreases until it stops. The time between starting up and the first stopping of the driving pendulum is the half-oscillation period, which is a function of the longitudinal (Young) modulus of elasticity of the specimen in alternating flexure.

B.1.3.4 ISO 6721-1, *Plastics — Determination of dynamic mechanical properties — Part 1: General principles*

A good introduction is provided to the various terms used, the relationship between the moduli, types of oscillatory modes and modes of deformation, and simplified diagrams of the commonly used specimen test arrangements. ISO 6721-1 is similar to ISO 4664-1 (B.1.2.1) for rubber.

B.1.3.5 ISO 6721-2, *Plastics — Determination of dynamic mechanical properties — Part 2: Torsion-pendulum method*

A long strip of material of uniform cross-section is fixed at one end, and the free end with added mass is set into a twisting torsion motion and allowed to decay freely. The period of vibration and its decay determine the shear modulus. The test is primarily used to determine the rubbery transition region by making measurements over a wide temperature range. The test frequency is low, typically from 0,1 Hz to 10 Hz, and varies with temperature. ISO 6721-2 is similar to ISO 4664-2 (B.1.2.2) for rubber.

B.1.3.6 ISO 6721-3, *Plastics — Determination of dynamic mechanical properties — Part 3: Flexural vibration — Resonance-curve method*

A specimen is forced into a bending motion and the flexural modulus determined from the resonance curve. The resonant frequency and specimen parameters determining the storage modulus and the loss are determined by the width of the resonance peak. Two test arrangements providing two modes of vibration are described. The frequency range is 10 Hz to 1 000 Hz. ISO 6721-3:1994, Annex A contains the results of round-robin testing on three plastics.

B.1.3.7 ISO 6721-4, *Plastics — Determination of dynamic mechanical properties — Part 4: Tensile vibration — Non-resonance method*

A specimen is clamped at both ends. A forced non-resonant vibration displacement is measured at one end, and the other end is attached to a force gauge and rigid mount. Measurements are made below the primary resonant frequency of the specimen and force transducer. There are corrections for the effects of the clamps. This is also known as the direct method, as the specimen end motion is blocked by a rigid termination versus the indirect method in which one end is free to vibrate.

B.1.3.8 ISO 6721-5, *Plastics — Determination of dynamic mechanical properties — Part 5: Flexural vibration — Non-resonance method*

A specimen is either simply supported at the two ends or clamped and vibrated at its centre. A measure of the force and displacement at the centre provides a measure of the apparent Young modulus and, with corrections, the actual modulus. The frequency range is 0,01 Hz to 100 Hz, which is typical for a dynamic mechanical analyser (DMA), although the mode of vibration is different in a DMA which is a cantilever shear deformation.

