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

Part 4: Dynamic stiffness method

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

Partie 4: Méthode de la raideur dynamique

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 18437-4 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 2: Resonance method*

— *Part 3: Cantilever shear beam method*

— *Part 4: Dynamic stiffness method*

The following parts are under preparation:

— *Part 1: Principles and guidelines*

— *Part 5: Poisson's ratio based on finite element analysis*

Introduction

Visco-elastic materials are used extensively to reduce vibration magnitudes, of the order of hertz to kilohertz, in structural systems through dissipation of energy (damping) or isolation of components, and in acoustical applications that require modification of the reflection, transmission, or absorption of energy. The design, modelling and characterization of such systems often require specific dynamic mechanical properties (the Young, shear, and bulk moduli and their corresponding loss factors) 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, and strain amplitude. The choice of a specific material for a given application determines the system performance. The goal of this part of ISO 18437 is to provide details, in principle, of the operation of the direct dynamic stiffness method, the measurement equipment used in performing the measurements, and the analysis of the resultant data. A further aim is to assist users of this method and to provide uniformity in the use of this method. This part of ISO 18437 applies to the linear behaviour observed at small strain amplitudes, although the static stiffness may be non-linear.

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

Part 4: Dynamic stiffness method

1 Scope

This part of ISO 18437 specifies a direct method for measuring the complex dynamic moduli of elasticity (the Young, shear and bulk moduli, and their respective loss factors corresponding to the tensile, shear and all compressive strains) for polymeric (rubbery and viscous polymers, as well as rigid plastics) materials over a wide frequency and temperature range. Measurements are performed by the dynamic stiffness method, which uses electric signals from sensors attached to a test piece. These signals are proportional to the dynamic forces acting on the test piece and the strains in the test piece due to the effect of these forces.

The measurement frequency range is determined by the size of test piece, the accuracy required on the dynamic modulus measurements, the relationship between the stiffness of the oscillation generator and the stiffness of the test piece, and by the resonance characteristics of the test fixture used.

The method presented in this part of ISO 18437 allows measurement under any static pre-load allowed for the test piece (including the test piece having the non-linear characteristics under different static loads), but under small dynamic (acoustic) strains, *i.e.*, in limits where the linear properties of the test piece are not distorted. Depending on the pre-load conditions, the relation between the moduli is unique.

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 472, *Plastics — Vocabulary*

ISO 483, *Plastics — Small enclosures for conditioning and testing using aqueous solutions to maintain the humidity at a constant value*

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

ISO 6721-6, *Plastics — Determination of dynamic mechanical properties — Part 6: Shear vibration — Non-resonance method*

ISO 10112, *Damping materials — Graphical presentation of the complex modulus*

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

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

NOTE ISO 10846-1 is concerned with the global measurement of dynamic input and transfer stiffness and mechanical resistance of resilient fixtures. This part of ISO 18437 is concerned with the characterization of the dynamic Young modulus, shear modulus, bulk modulus, and corresponding loss factors of the visco-elastic materials that are used in the fixtures.

3 Terms and definitions

For the purposes of this part of ISO 18437, the terms and definitions given in ISO 472, ISO 483, ISO 2041, ISO 4664-1, ISO 6721-1, ISO 6721-4, ISO 6721-6, ISO 10112, ISO 10846-1, ISO 23529, and the following apply.

3.1
dynamic mechanical properties
⟨visco-elastic materials⟩ fundamental elastic properties, *i.e.*, elastic modulus, shear modulus, bulk modulus and loss factor

3.2
damped structure
structure containing elements made from damping materials

3.3
Young modulus
modulus of elasticity
E
ratio of the normal stress to linear strain

NOTE 1 Adapted from ISO 80000-4-18.1:2006[9].

NOTE 2 The Young modulus is expressed in pascals.

NOTE 3 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.

3.4
shear modulus
modulus of rigidity
Coulomb modulus
G
ratio of the shear stress to the shear strain

NOTE 1 Adapted from ISO 80000-4-18.2:2006[9].

NOTE 2 The shear modulus is expressed in pascals.

NOTE 3 The complex shear modulus, G^*, for a visco-elastic material is represented by $G^* = G' + \mathrm{i}G''$, where G' is the real (elastic) component of the shear modulus and G'' is the imaginary (loss modulus) component of the shear modulus.

3.5
bulk modulus
modulus of compression
K
the negative ratio of pressure to volume strain

NOTE 1 Adapted from ISO 80000-4-18.3:2006[9].

NOTE 2 The bulk modulus is expressed in pascals.

NOTE 3 The complex bulk modulus is represented by $K^* = K' + iK''$, where K' is the real (elastic) component of the bulk modulus and K'' is the imaginary (loss modulus) component of the bulk modulus.

3.6
loss factor
ratio of the imaginary component to the real component of a complex modulus

NOTE When a material shows a phase difference, δ, between dynamic stress and strain in harmonic deformations, the loss factor is equal to tanδ.

3.7
magnitude of complex modulus
absolute value of the complex modulus

NOTE The magnitude of the complex moduli are defined as:

a) magnitude of the Young modulus: $|E| = \sqrt{[(E')^2 + (E'')^2]}$;

b) magnitude of shear modulus: $|G| = \sqrt{[(G')^2 + (G'')^2]}$;

c) magnitude of bulk modulus: $|K| = \sqrt{[(K')^2 + (K'')^2]}$.

These magnitudes are expressed in pascals.

3.8
frequency-temperature superposition
principle by which, for visco-elastic materials, frequency and temperature are equivalent to the extent that data at one temperature can be superimposed upon data taken at different temperature merely by shifting the data curves along the frequency axis

3.9
shift factor
measure of the amount of shift along the logarithmic axis of frequency for one set of data at one temperature to superimpose upon another set of data at another temperature

3.10
glass transition temperature
T_g
⟨visco-elastic materials⟩ temperature at which a material changes state reversibly from glassy to rubbery

NOTE 1 The glass transition temperature is expressed in degrees Celsius.

NOTE 2 The glass transition temperature is typically determined from the inflection point of a specific heat vs. temperature plot and represents an intrinsic material property.

NOTE 3 T_g is not the peak in the dynamic mechanical loss factor. That peak occurs at a temperature higher than T_g and varies with the measurement frequency, hence it is not an intrinsic material property.

3.11
linearity
⟨visco-elastic materials⟩ property of dynamic behaviour of a resilient material if it satisfies the principle of superposition

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

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

4 Principle

The dynamic stiffness method is a technique for determining the frequency characteristics of the complex dynamic modulus of elasticity of resilient materials using small test pieces mounted in an appropriate test fixture.

Before performing the measurement, test pieces of the material are manufactured and placed in a test fixture where they are subjected to a strain with the help of a displacement actuator. The force transducer electric output is proportional to the force acting on the test piece; the displacement actuator electric input signal is proportional to the strain in the test piece. The test piece shall have dimensions such that its impedance is completely elastic in character over the total frequency range of interest. Hence the inertial component of this impedance shall be negligible in comparison with the elastic component. To meet this requirement, the test piece sizes shall be such that the first eigenfrequency should be three to five times larger than the upper frequency limit of measurement.

In the dynamic stiffness method, when using special fixtures, it is possible to apply the three different types of strain: the Young (tensile or compressive), shear, and bulk to the test piece and thus measure the three corresponding moduli of elasticity and their corresponding loss factors (when the displacement actuator generates deformation only along the test piece axis). The user can choose a test piece shape and fixture for applying an appropriate type of strain in each specific case.

When performing the measurement using the specific conditions detailed above, the general expression for determination of the complex elastic modulus, $E^*,G^*,K^*(f)$, has the form

$$E^*,G^*,K^*(f) = \alpha_{E,G,K}[F(f)/s(f)]. \quad (1)$$

where

$\alpha_{E,G,K}$ is the ratio of the measured modulus of the tested material to stiffness of the test piece under the appropriate strain (longitudinal, shear or bulk);

NOTE Methods of calculating $\alpha_{E,G,K}$ are shown in Clause 6.

$F(f)/s(f)$ is the complex ratio of the output force and the test piece displacement.

Hence, the real part of the modulus, E', G', $K'(f)$, is given by Equation (2):

$$E',G',K'(f) = \alpha_{E,G,K}\,\mathrm{Re}[F(f)/s(f)] \quad (2)$$

The imaginary part of the modulus, $E'',G'',K''(f)$, is given by Equation (3):

$$E'',G'',K''(f) = \alpha_{E,G,K}\,\mathrm{Im}[F(f)/s(f)] \quad (3)$$

The magnitude of the modulus, $\left|E,G,K\left(f\right)\right|$, is given by Equation (4):

$$\left|E,G,K\left(f\right)\right| = \alpha_{E,G,K}\left|F\left(f\right)/s\left(f\right)\right| \tag{4}$$

The loss factors, $\eta_{E,G,K}(f)$, are given by Equation (5):

$$\eta_{E,G,K}(f) = \mathrm{Im}[F(f)/s(f)]/\mathrm{Re}[F(f)/s(f)] \tag{5}$$

5 Equipment

5.1 Hardware

The following items are used for carrying out the measurements:

5.1.1 2-Channel fast Fourier transform (FFT) analyser, which provides a measurement of complex value frequency response function.

5.1.2 Input and output transducer, and **preamplifiers** as required.

5.1.3 Computer.

5.1.4 Test device and **test piece**, including force transducer and displacement actuator.

A temperature sensor (such as a thermocouple or thermostat) shall be placed in the test device when temperature dependence of moduli and loss factors is to be measured. The device for controlling the temperature of the test piece may be mounted inside the test device. The thermostat shall measure the actual temperature of the test piece over the range −60 °C up to +70 °C, at minimum increments of 5 °C.

5.2 Set-up

A typical measurement set-up and test device for measuring the visco-elastic characteristics, such as the dynamic moduli of elasticity and loss factors, of a polymeric material are shown in Figure 1 and Figure 2 respectively (Reference [1]). Depending on the test device and the material, the frequency range can be up to 10 kHz.

If the application of the visco-elastic material is for structure-borne noise or vibration suppression, it should be tested up to 500 Hz (see ISO 10846-1).

The test set-up comprises the following components:

- rigid restrictive construction;
- means of fixing or attaching test pieces to the test set-up;
- two electromechanical units, a displacement actuator and a force transducer — the former converts the electrical signal from the power amplifier into a surface displacement that is in contact with the test piece and deforms it, while the latter converts the force acting on the test piece into an electric signal (see Figure 2);
- annular washers for adjustment of the gap between the force transducer and the displacement actuator when carrying out test piece measurements under any permissible static pre-load;
- external fixture to generate a known static compression in the test piece when attached to the electromechanical units.