45

INTERNATIONAL STANDARD ISO 2856

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Elastomers – General requirements for dynamic testing

Élastomères – Spécifications générales pour essais dynamiques

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FOREWORD

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Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

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It has been approved by the Member Bodies of the following countries :

Australia	Hungary	South Africa, Rep. of
Austria	India	Spain
Belgium	Italy	Sweden
Brazil	Mexico	Switzerland
Canada	Netherlands	Thailand
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France	Portugal	U.S.S.R.
Germany	Romania	

No Member Body expressed disapproval of the document.

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CONTENTS

Page

Elastomers – General requirements for dynamic testing

1 SCOPE AND FIELD OF APPLICATION

This International Standard gives definitions and specifies quantitative conditions and general requirements for test pieces, testing machines and test procedures for determining viscoelastic parameters of elastomers by application of cyclic forces or deformation of controlled form, frequency and amplitude, including impact forces or deformations. The term 'dynamic properties' is here used to characterize the deformation behaviour of elastomers under conditions when both stress and strain vary perodically with time.

This International Standard is oriented towards the use of laboratory prepared test pieces but the same principles usually apply to tests on finished products or their models.

A summary of basic concepts and theory of dynamic properties of elastomers, with selected references, is included to clarify the definitions and interpretation of data.

2 TERMS AND RELATIONSHIPS USED TO DEFINE DYNAMIC PROPERTIES OF ELASTOMERS

Each of the following terms and relationships applies to linear models of elastomer behaviour.

It is recommended that the unqualified term 'modulus' should not be used. The term 'modulus' should be prefaced as in, for example, 'elastic shear modulus'. Bulk or hydrostatic compression modulus of elastomers is several orders of magnitude larger than the deformation moduli considered here, and is not dealt with in this International Standard. Shear and normal moduli are material properties of the rubber vulcanizate and are independent of the size and shape. In contrast, spring constant and damping constant are dependent upon geometry (shape and size) and are usually applied to whole products, such as bushings, mounts, and tyres.

Finally, the use of SI units in their basic form is recommended; these are accordingly given for the terms defined below.

2.1 TERMS APPLYING TO ANY PERIODIC MOTION

2.1.1 mechanical hysteresis loop : The closed curve representing successive stress-strain states of the material during a cyclic deformation.

NOTE — Loops may be centred around the origin of co-ordinates or more frequently displaced to various levels of strain or stress; in this case the shape of the loop becomes variously asymmetrical, but this fact is frequently disregarded.

2.1.2 energy loss (J/m^3) : The energy per unit volume which is lost in each deformation cycle. It is the hysteresis loop area, calculated with reference to co-ordinate scales.

2.1.3 power loss (W/m^3) : The power per unit volume which is transformed into heat through hysteresis. It is the product of energy loss and frequency.

2.1.4 mean stress (Pa) : The average value of the stress during a single complete hysteresis loop (see figure 1).

2.1.5 mean strain (dimensionless) : The average value of the strain during a single complete hysteresis loop (see figure 1).

2.1.6 mean modulus (Pa) : The ratio of mean stress to mean strain.

2.1.7 stress amplitude (Pa) : The ratio of the maximum applied force, measured from the mean force, to the cross-sectional area of the unstressed test piece (zero to peak on one side only).

2.1.8 root-mean-square stress (Pa) : The square root of the mean value of the square of the stress averaged over one cycle of deformation. For a symmetrical sinusoidal stress the root-mean-square stress equals the stress amplitude divided by $\sqrt{2}$.

2.1.9 strain amplitude (dimensionless) : The ratio of the maximum deformation, measured from the mean deformation, to the free length of unstrained test piece (zero to peak on one side only).

2.1.10 root-mean-square strain (dimensionless) : The square root of the mean value of the square of the strain averaged over one cycle of deformation. For a symmetrical sinusoidal strain the root-mean-square strain equals the strain amplitude divided by $\sqrt{2}$.

2.2 TERMS APPLYING TO SINUSOIDAL MOTION

Sinusoidal motion implies hysteresis loops which are or can be considered to be elliptical. The term 'incremental' may be used to designate dynamic response to sinusoidal motion about various levels of mean stress or mean strain (for example, incremental spring constant, incremental elastic shear modulus).

For large sinusoidal deformation, the hysteresis loop will deviate from an ellipse since the stress-strain relationship of rubber is non-linear and the motion is no longer sinusoidal.

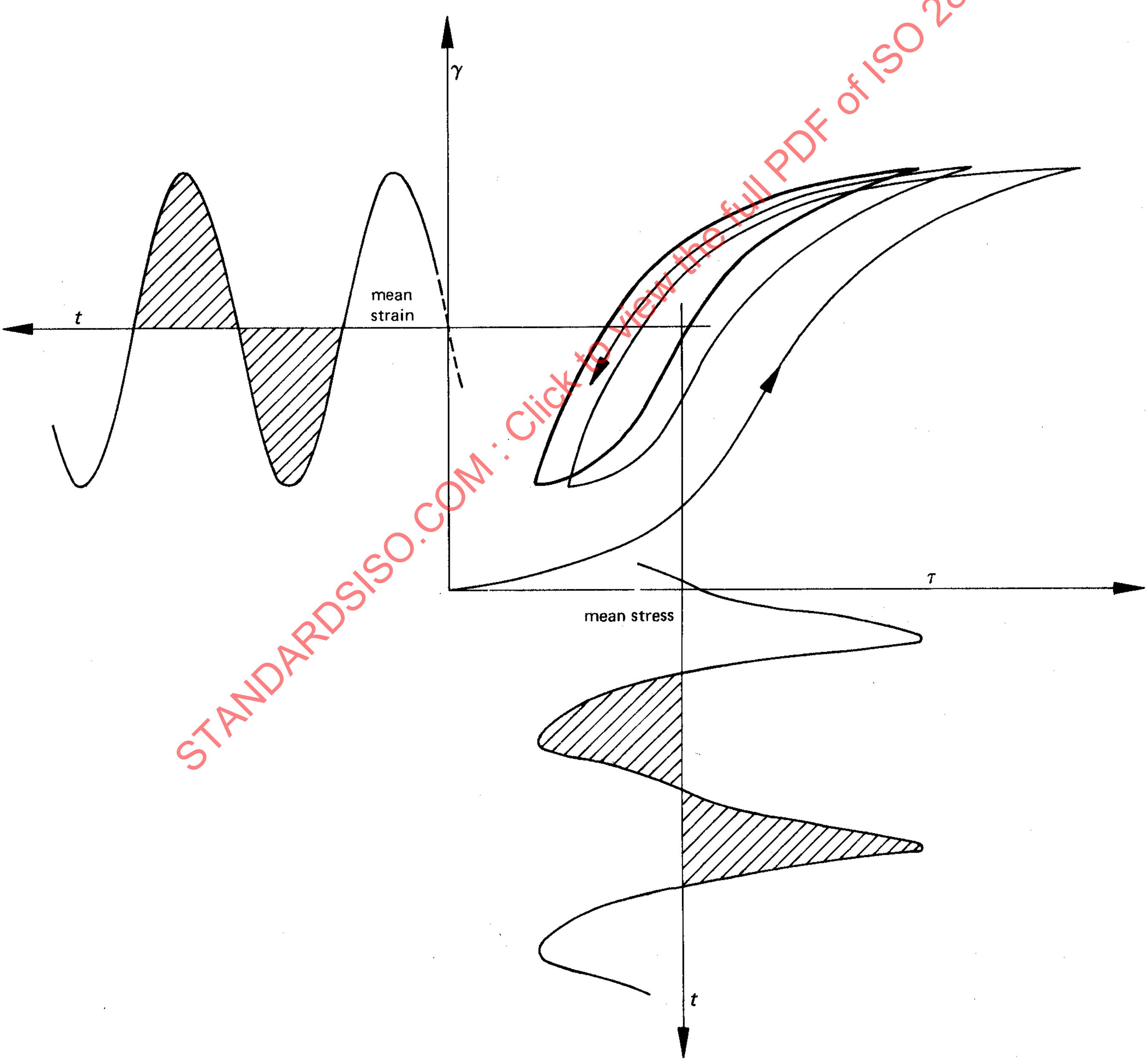

FIGURE 1 — **Heavily distorted hysteresis loop obtained under forced pulsating sinusoidal strain. Open initial loops are shown as well as equilibrium mean strain and mean stress as time-averages of instantaneous strain and stress**

2.2.1 spring constant k (N/m) : The component of applied force which is in phase with the deformation, divided by the deformation.

2.2.2 elastic shear modulus (storage shear modulus) G' (Pa) : The component of applied shear stress which is in phase with the shear strain, divided by the strain.

2.2.3 elastic normal modulus (storage normal modulus; elastic Young's modulus) E' (Pa) : The component of applied normal stress which is in phase with the normal strain, divided by the strain.

2.2.4 damping constant c (N·s/m) : The component of applied force which is in quadrature with the deformation, divided by the velocity of deformation.

2.2.5 loss shear modulus G'' (Pa) : The component of applied shear stress which is in quadrature with the shear strain, divided by the strain.

2.2.6 loss normal modulus (loss Young's modulus) E'' (Pa) : The component of applied normal stress which is in quadrature with the normal strain, divided by the strain.

2.2.7 complex shear modulus $G^* = G' + jG''$ (Pa) : The ratio of the shear stress to the shear strain, where each is a vector which may be represented by a complex number.

2.2.8 complex normal modulus (complex Young's modulus) $E^* = E' + jE''$ (Pa) : The ratio of the normal stress to the normal strain, where each is a vector which may be represented by a complex number.

2.2.9 absolute (value of) complex shear modulus $G^* = |G^*| = \sqrt{G'^2 + G''^2}$ (Pa) : The magnitude of the complex shear modulus.

2.2.10 loss factor $\tan \delta$ (dimensionless) : The ratio of loss modulus to elastic modulus. For shear stresses, $\tan \delta = G''/G'$ and for normal stresses, $\tan \delta = E''/E'$.

2.2.11 loss angle δ (rad) : The phase angle between stress and strain, the tangent of which is the loss factor.

2.3 TERMS APPLYING TO OTHER MOTION

2.3.1 logarithmic decrement Λ (dimensionless) : The natural (naperian) logarithm of the ratio between successive amplitudes of the same sign of a damped oscillation.

2.3.2 damping ratio u (dimensionless) : The ratio of actual to critical damping where critical damping is that required for the borderline condition between oscillatory and non-oscillatory behaviour. Damping ratio is a function of the logarithmic decrement :

$$u = \frac{\Lambda/2\pi}{\sqrt{1 + (\Lambda/2\pi)^2}} = \sin \arctan (\Lambda/2\pi)$$

For small values of Λ it is : $u = \Lambda/2\pi$

2.3.3 rebound resilience R (dimensionless) : After a succession of impacts, when steady state is reached, the ratio of the output to the input energy of a moving mass which impacts the test piece.

3 REFERENCES

ISO 471, *Rubber – Standard temperatures and humidities for the conditioning and testing of test pieces.*[1]

ISO 1826, *Rubbers – Time-lapse between vulcanization and testing.*

ISO 3383, *Rubber – General directions for achieving elevated or sub-normal temperatures for tests.*[2]

ISO . . ., *Rubber – Preparation of test pieces.*[3]

4 GENERAL INFORMATION ABOUT TESTING MACHINES

Testing machines may provide impacts or cyclic oscillations in various ranges of stress or strain amplitudes, frequencies, and temperatures[6][19]. Machines which operate at frequencies above 500 Hz or with which distributed vibrations occur are not considered here. Often two or more types of machine will be needed to cover the desired range of operating conditions.

Testing machines may be classified as follows :

1) Type of motion
   - Cyclic resonant oscillations
   - Cyclic non-resonant oscillations
   - Rolling, pulsed deflection
   - Free, damped oscillation
   - Impact

2) Imposed quantity
   - Strain
   - Stress
   - Energy

1) At present at the stage of draft. (Revision of ISO/R 471.)

2) At present at the stage of draft.

3) In preparation.

3) Frequency range covered

– Static and low frequency < 1 Hz

– Medium frequency 1 to 100 Hz

– High frequency > 100 Hz

5 TESTING MACHINE REQUIREMENTS

Only general requirements for dynamic testing machines are considered here. Construction shall, of course, be sturdy and precise. Response shall be unaffected by machine resonances within the test frequency range, or spurious vibrations of either internal or external origin. The imposed amplitude and frequency shall be constant and, where necessary, adjustable.

Readings or recordings, whether by mechanical, optical or electrical means, shall have adequate sensitivity, linearity and absence of effects due to such extraneous variables as temperature. If measurements are to be made at other than ambient temperature, an adequately thermostatted housing operating in accordance with ISO 3383 shall be provided for at least the test piece holder. A temperature measuring system shall be provided and properly operated. For adequate description of test piece temperature this may involve transducers such as internal and external thermocouples or thermistors with appropriate indicating or recording devices.

6 RECOMMENDED STANDARD TEST VALUES

Because of the complex viscoelastic behaviour of elastomers, results of dynamic measurements are highly sensitive to test conditions such as temperature, frequency, and amplitude of applied force or deformation (see annex D). Test piece shape is also important (see clause 7).

Either stress or strain amplitude must be specified, and also either mean stress or mean strain.

Conditions for standard tests shall agree with those given in this clause.

6.1 Temperature (°C)

Nominal temperatures shall be selected from the following (°C) :

– 75	+ 70
– 55	+ 85
– 40	+ 100
– 25	+ 125
– 10	+ 150
0	+ 175
+ 23	+ 200
+ 27	+ 225
+ 40	+ 250
+ 50	

The actual temperature anywhere in the test piece shall not differ from the nominal value by more than a set tolerance. This is normally ± 2 °C but may be narrowed to ± 0,5 °C near a transition temperature, or widened when high frequencies or high amplitudes are involved. The tolerance must be stated in the test report (see clause 10).

6.2 Form and type of impressed strain and stress

The preferred form of impressed strain or stress is sinusoidal. Shear strains and stresses are preferable but normal ones are acceptable if reasonably homogenous (see 7.2). Sinusoidal strain or stress shall be impressed on the test piece with harmonic distortion as low as possible, and in no case greater than 10 %. Dynamic stress or strain may be superposed on any level of mean stress or strain, including zero.

Other acceptable forms of impressed strain or stress are : free damped oscillations with a logarithmic decrement less than 1,0, periodic half-sinusoidal cycles, and impacts.

6.3 Frequency and amplitudes

Frequency, strain amplitude and stress amplitude ranges may include only a few points or up to several decades, depending on test objectives. It is recommended that these experimental parameters be varied in a logarithmic manner. The following scales, given by way of example, may be extended at either end through multiplication by appropriate negative or positive powers of 10.

Scale A : 1, 10
Scale B : 1, 3, 10
Scale C : 1, 2, 5, 10
Scale D : 1, 1,5, 2, 3, 5, 7, 10

6.3.1 Frequency (Hz)

Frequency tolerance shall be ± 2 % of the nominal value. No frequency higher than 500 Hz is considered here.

6.3.2 Strain amplitude (dimensionless)

Strain amplitude tolerance shall be ± 5 % of the nominal value.

6.3.3 Stress amplitude (Pa)

Stress amplitude tolerance shall be ± 5 % of the nominal value.

6.4 Mean strain or stress (pre-loading)

The direction of pre-loading is not restricted to that of the alternating strains or stresses. Values and tolerances shall be selected as for the alternating values.

6.5 Single reference value

If, for reference purposes, a single set of parameters is required, this set shall be :

temperature	50 °C
form and type of impressed strain	sinusoidal shear
frequency	10 Hz
strain amplitude	0,1
mean	zero

7 TEST PIECES

Although the overall size of the test piece will affect the internal temperature rise during test, this is also influenced by other factors (see 8.4), and hence absolute dimensions are not specified.

However, the test piece shape and the way in which the force is applied directly affect the stress distribution and hence the modulus values obtained experimentally. Both of these are specified (see 7.2.3).

7.1 Test piece preparation

Test pieces shall be prepared in general accordance with ISO . . .

Preferably, test pieces shall be suitably moulded and vulcanized. Metal end pieces shall be attached with vulcanizing bonding agents. Care shall be used to obtain very uniform vulcanization, especially with thick test pieces.

Alternatively, test pieces may be obtained from finished articles by cutting and buffing. Suitable cold-setting cement shall be used for bonding such test pieces to metal end pieces.

7.2 Shape of test piece and type of strain

An ideal test piece will give a homogenous distribution of stress and strain. In practice, however, this is rarely the case. Hence, suitable analytical or empirical analyses shall be used to correct the results obtained experimentally.

7.2.1 *Analysis of deformation*

Unless otherwise stated, analysis of test piece deformation shall follow a first approximation statistical or phenomenological theory of rubber elasticity. The following expressions relate to the elastic component of the modulus. Analogous expressions for the loss component can be derived by references to annexes B and C.

For sheared test pieces, equation 1 shall be used.

$$\tau = \Phi_s G \gamma \qquad \ldots (1)$$

where

τ is the shear stress;

G is the modulus (shear);

γ is the shear strain;

Φ is a shape factor.

For extended or compressed pieces, equation 2 shall be used.

$$\sigma \approx \Phi_s E (\lambda - 1) \qquad \ldots (2)$$

where

σ is the normal stress referred to initial section;

λ is the extension ratio (actual length/initial length).

This approximate relation is true only if λ is near unity, certainly not outside the range 0,8 to 1,2.

If a more accurate deformation analysis such as that in annex B is used, this shall be specified in the test report.

7.2.2 *Non-homogeneous deformation shape factors*

Any non-homogeneity of deformation shall be recognized by using suitable shape factors or functions[24].

Preference shall be given to expressions not containing, explicitly or implicitly, the moduli or other quantities to be determined.

7.2.3 *Recommended shapes and shape factors*

7.2.3.1 SHEARED SQUARE PRISM

The base side b shall be four times the height h. Shear force shall be applied to the bases and parallel to one of the base sides.

Use equation 1 of 7.2.1 with a shape factor $\Phi_s = 1{,}0$ so that

$$\tau = G \gamma$$

7.2.3.2 SHEARED CIRCULAR CYLINDER

The radius r shall equal the height h. Shear force shall be applied to the circular faces parallel to a diameter.

Use equation 1 of 7.2.1 with a shape factor $\Phi_s = 0{,}9$ so that

$$\tau = 0{,}9\, G \gamma$$

7.2.3.3 NORMALLY STRAINED SQUARE PRISM

The base side b shall be twice the height h. Normal force shall be applied to the bases and parallel to the height.

Use equation 2 of 7.2.1, with the stated limitations on λ, with a shape factor $\Phi_s = 1{,}5$ so that

$$\sigma \approx 1{,}5\, E (\lambda - 1)$$

7.2.3.4 NORMALLY STRAINED CIRCULAR CYLINDER

The radius r shall equal one-half the height h. Normal force shall be applied to the bases parallel to the height.

Use equation 2 of 7.2.1, with the stated limitations on λ, with a shape factor $\Phi_s = 1{,}1$ so that

$$\sigma \approx 1{,}1\, E (\lambda - 1)$$

7.2.3.5 TORUS

The torus[15], having pseudotrapezoidal section, shall be bounded internally by a cylindrical surface of radius r_i and externally by a cylindrical surface of radius $r_e = 1{,}2\, r_i$ and thickness $h_e = r_e/6$. The lateral surface shall be hyperboloidal and defined by the relation :

$$r^2 h = r_e^2 h_e = \text{constant}$$

where r and h are any corresponding radius and thickness. Axial torque shall be applied to the cylindrical surfaces.

Use equation 1 of 7.2.1 with a shape factor $\Phi_s = 1{,}0$ so that

$$\tau = G\gamma$$

7.2.3.6 Rotating deflected wheel

The wheel, width b and external radius r_e, shall be bonded to a metal core, radius r_i. It shall roll, loaded with force F, on a drum radius not larger than r_e and appreciably wider than h.

Deflection d shall not be more than 0,1 $(r_e - r_i)$.

For materials whose dependence of elastic modulus on impressed amplitude is small (see clause D.2 of annex D), the shear modulus is given by the relation :

$$G = \frac{F\,(r_e - r_i)}{4\,b\,r_e^{0,5}\,d^{1,5}}$$

A more detailed analysis[16] is required for the determination of the elastic modulus of materials which are amplitude-dependent, and for the determination of the loss modulus.

7.2.3.7 Indented disk

Standard disk thicknesses shall be : 2 ± 0,2; 4 ± 0,2; 6,3 ± 0,3 and 12,5 ± 0,5 mm, as specified in the appropriate test procedure.

An identor shall move normal to the flat disk face, contacting it by impact or alternating motion[26].

A first approximation spring constant of the identor-disk system, neglecting the effect of finite thickness of the disk, is :

spherical indentor $k = 3{,}5GD^{0,65}\,d^{0,35}$

circular flat indentor $k = 4GD$

where

k is the spring constant;

G is the shear modulus;

D is the indentor diameter;

d is the indentation depth.

7.2.3.8 Twisted strip

The strip shall have a rectangular cross-section of width b and thickness h $(b \geqslant h)$. It shall be bonded or clamped at the ends, leaving a free length l $(l \geqslant 10\,b)$. The strip shall be twisted through angle α by a torque Q.

If $b \geqslant 3\,h$, use the approximation :

$$G = \frac{3Ql}{\alpha b h^3\,(1 - 0{,}63\,h/b)}$$

If $b < 3\,h$, use an exact formula[8].

7.2.3.9 Twisted cylinder

The cylinder, bonded or clamped at the ends, with free length l at least ten times the radius r, shall be twisted axially through angle α by torque Q. In this case :

$$G = \frac{2Ql}{\pi \alpha r^4}$$

7.2.3.10 Extended rectangular or circular rod

The rod shall have a length of at least eight times the diameter or width and shall be bonded on both ends. Deformation shall be in tension.

Use equation 2 of 7.2.1 with a shape factor $\Phi_s = 1{,}0$.

8 TEST PIECE CONDITIONING

8.1 Storage of test pieces

The time-lapse between vulcanization and testing shall be in accordance with ISO 1826.

8.2 Conditioning

Test pieces shall be conditioned immediately before testing in one of the standard laboratory temperatures in accordance with ISO 471. All measurements or checking of test piece dimensions shall be carried out at that temperature.

8.3 Structural rearrangements

Dynamic measurements shall be made only after at least six cycles of stress have been applied to the test pieces. This is to permit internal structural rearrangements to reach near equilibrium so that the results are reproducible.

8.4 Temperature

Test pieces shall be conditioned at the test temperature for a long enough time to reach internal equilibrium in accordance with ISO 3383.

No restriction on the time between application of stress and taking readings is necessary for low amplitude and low frequency conditions where heat build-up due to hysteresis does not cause the standard temperature tolerance (see 7.1) to be exceeded. For higher amplitudes and frequencies, readings may be made either before the temperature tolerance has been exceeded (instant method) or after temperature equilibrium has been reached (steady state method). In the latter method, test piece dimensions shall be kept as small as possible and adequate temperature transducers shall be used to obtain the average test piece temperature and its deviation at various points. This procedure, while less desirable for determination of basic dynamic properties of materials, is generally more appropriate for finished products or models of them.

Only the instant method may be used when amplitudes and frequencies are severe enough to cause early test piece failure. In some cases use of this procedure may require special recording apparatus.

8.5 Fatigue and other deteriorations

The effects of the fatigue and deterioration consequent upon the prolonged application of repeated deformations or of high temperatures can radically alter the measured values of the dynamic properties. The measurement of such changes is not within the scope of this International Standard.

8.6 Test schedule

If a single piece is to be tested under more than one set of conditions, measurements shall begin with the least severe conditions then proceed to larger amplitude and higher frequency. In case of testing at different temperatures, the test cabinet shall be adjusted to the lowest specified temperature and after the test pieces have been tested at this temperature the temperature shall be increased to the next test temperature. For any one set of test conditions the specified stress or strain amplitude shall never be exceeded in preliminary adjustments or during the course of the test unless such treatment is part of a deliberate pre-conditioning or testing plan. If there is uncertainty concerning the effect of any treatment upon results, including possible interactions with other treatments, such treatment shall be systematically investigated to determine quantitatively the effect.

9 DATA

Test piece dimensions and pertinent masses, distances, strokes, torques and temperatures required for interpretation of results shall be known.

9.1 Impact machines

Data sufficient for calculation of the rebound resilience R shall be obtained. Normally, these are the rest position of the mass before impact and its position at maximum rebound. The time of contact between the mass and the test piece is required for calculation of the elastic modulus and internal viscosity (see clause C.4 of annex C).

9.2 Damped oscillation machines

Recording of the complete damped oscillation is recommended for determining the frequency f and the logarithmic decrement Λ. These quantities, together with test piece dimensions, are sufficient to calculate moduli and viscosity (see clause C.3 of annex C).

9.3 Cyclic oscillation machines

9.3.1 *Resonance machines*

Normally, frequency, amplitude at resonance and driving force at resonance are determined. It is also necessary to determine whether the resonance corresponds to a maximum amplitude of force, deflection or stored energy in order to calculate moduli.

9.3.2 *Non-resonant machines*

Preferably, a complete recording of the stress-strain hysteresis loop should be made, after the attainment of cyclic conditions (see 8.3). Although the traced hysteresis loop may not be elliptical for large strains (see figure 2), it is conventionally considered to be equivalent to an ellipse having the same stress and strain amplitudes and the same area expressed as energy loss.

Using this analysis,

$$|G^*| = T/\Gamma$$

$$G' = \pi^2 T^2 \Gamma^2 = A^2/\pi\Gamma^2$$

$$G'' = A/\pi\Gamma^2$$

$$= \sin^{-1}(A/\pi T \Gamma)$$

If greater accuracy is desired in highly non-elliptical loops, phase plane analysis[20] can be used.

If a complete recording of the hysteresis loop is not possible, then at least the stress and strain amplitudes must be determined together with the phase difference between them. In this case :

$$|G^*| = T/\Gamma$$

$$G' = G^* \cos\delta$$

$$G'' = G^* \sin\delta$$

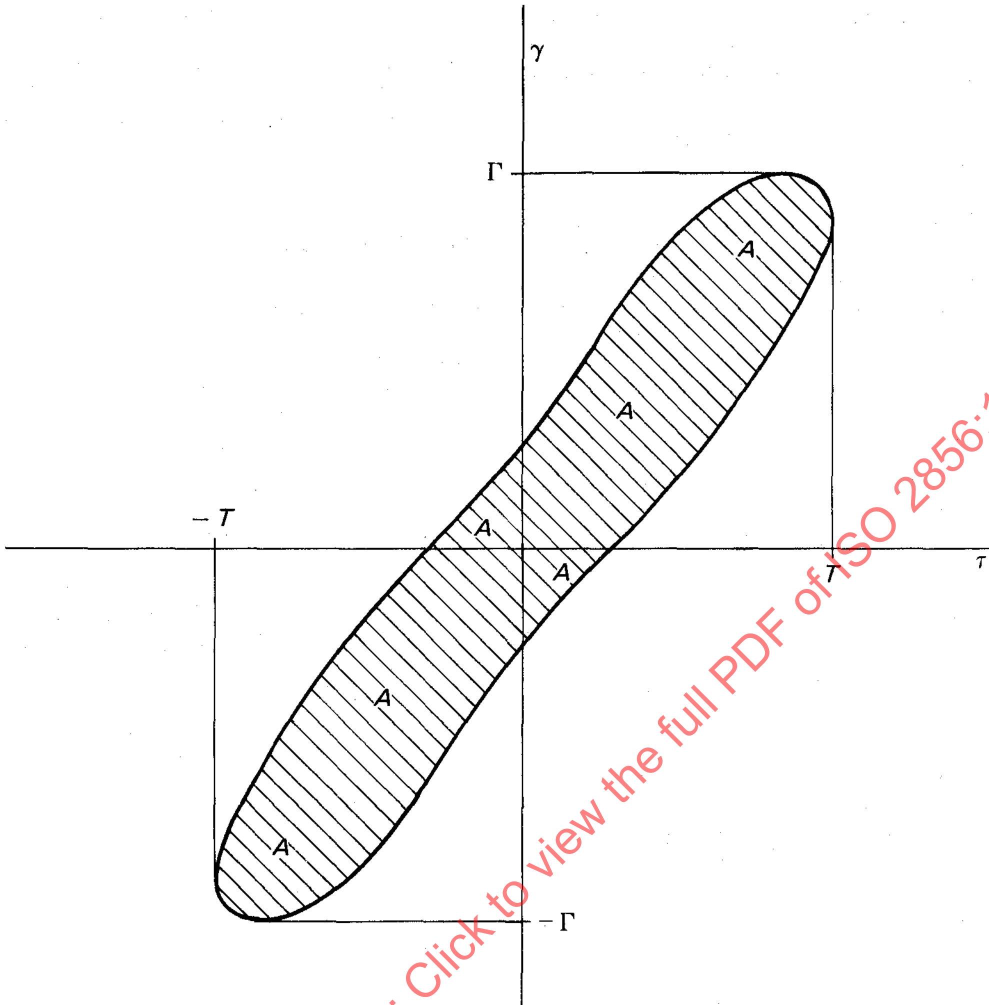

FIGURE 2 – **Non-elliptical loop. Amplitudes of strain Γ and *T* are indicated; geometrical area must be multiplied by abscissae and ordinates scales in order to obtain value *A* to be introduced in the calculations**

10 TEST REPORT

The test report shall include the following particulars :

a) a reference to this International Standard;

b) a full description of the sample and any relevant facts about its pre-test history;

c) the method of preparation of the test pieces, for example whether moulded or cut;

d) the curing conditions applied to the test pieces, if known;

e) the method of attaching metal end pieces to the test pieces;

f) the time and temperature of conditioning of the test pieces prior to testing;

g) the type of machine used;

h) the test method adopted;

i) the form and dimensions of the test pieces;

j) the number of test pieces tested;

k) the strain type;

l) the test frequencies;

m) the test temperatures and tolerances;

n) the wave form and amplitude of strain, stress or energy input;

o) the break-in prior to recording data;

p) any non-standardized procedures adopted;

q) any special methods or assumptions in calculation;

r) the complex modulus values expressed as G' and G'' or as $|G^*|$ and tan δ for shear modulus or as E' and E'' or $|E^*|$ and tan δ for normal modulus.

s) the date of test.

ANNEX A

BASIC CONCEPTS

A.1 GENERAL CONCEPTS ON ELASTOMER CONSTITUTION

Elastomers consist of long chain molecules. Above the glass transition temperature, molecular segments can move relative to adjacent segments and are subject to fluctuations of position due to their thermal energy. The long molecules are entangled and, when crosslinked at infrequent intervals, form a deformable continuous network.

The unstrained molecules have maximum entropy; that is they are coiled with maximum disorder. External forces reduce this disorder and entropy by causing less probable configurations of the molecules. The network tends to return to initial conditions showing reversible stress-strain behaviour.

A.2 ELASTOMERIC VISCOELASTICITY

Simplified treatment of the preceding concepts leads to an elastic shear modulus proportional to the number of chains per unit volume and to the absolute temperature. This type of 'rubber elasticity' is limited to the amorphous network under strictly equilibrium or reversible conditions. It is modified when fillers are added especially in large quantity. Departure from simple theory can also occur at large strains in those polymers for which exchange forces between chains produce ordering or crystallization.

External stress changes the configuration of every chain in the affected volume of elastomer, producing co-ordinated movements of adjacent links. This involves energy losses, or hysteresis losses, analogous to viscous losses in liquids. Elastomer viscosity is affected by molecular mass, molecular free volume, temperature, and deformation rate.

ANNEX B

RELATIONS BETWEEN STRESS AND STRAIN

B.1 ELASTIC COMPONENT

Elementary rubber elasticity theory leads to the following relations :

$$G\,(\lambda_1^2 - \lambda_3^2) = \sigma_1{}' - \sigma_3{}'$$
$$G\,(\lambda_2^2 - \lambda_3^2) = \sigma_2{}' - \sigma_3{}'$$

where

$\sigma_1{}'$, $\sigma_2{}'$ and $\sigma_3{}'$ are the principal stresses referred to actual sections;

λ_1, λ_2 and λ_3 are ratios between strained and unstrained dimensions (extension ratios);

G is the shear modulus.

This result may be applied to different types of homogeneous strain; for simple shear it becomes :

$$\tau_e = G\gamma \qquad \ldots (1)$$

where

τ_e is the shear elastic stress;

γ is the shear strain.

For linear extension or compression it becomes :

$$\sigma_e = G\left(\lambda - \frac{1}{\lambda^2}\right)$$

where σ_e is the elastic stress referred to initial rather than actual section.

The preceding expression may variously be developed for values of λ not much different from unity; the following may be used if λ is in the range 0,7 to 1,3 :

$$\sigma_e = 3G\,\frac{\lambda - 1}{\lambda}$$

or else, the normal strain being $\epsilon = \lambda - 1$ and observing that in this limited range a constant normal modulus $E = 3G$ may be assumed, it is also :

$$\sigma_e = E\,\frac{\epsilon}{1 + \epsilon}$$

Further limiting (see 7.2.1) the range of λ around unity, the non-linearity of the preceding expressions may be totally eliminated as follows :

$$\sigma_e = E\epsilon = E(\lambda - 1) \qquad \ldots (2)$$

B.2 VISCOUS COMPONENT

For a first approximation, Newtonian fluid relations are valid. Then viscous shear stress τ_v is proportional to the time derivative $\dot{\gamma}$ of shear strain :

$$\tau_v = \eta\dot{\gamma} \qquad \ldots (3)$$

with the constant of proportionality η being the viscosity.

An approximate expression[6] for viscous normal stress σ_v in extension or compression is :

$$\sigma_v = 3\eta\dot{\lambda} \qquad \ldots (4)$$

B.3 SHAPE FACTORS

If strain is not homogeneous throughout the test piece, the preceding equations apply only locally. Compensation for non-homogeneity in a compressed or sheared piece is normally provided by a "shape factor". This was originally defined as the ratio between strained or transverse section and free or lateral area. More commonly, however, it is taken only as a suitable function of the shape of the piece[24].

When the appropriate shape factor Φ_s is considered, equations (1) to (4) become :

$$\tau_e = \Phi_s\, G\gamma$$
$$\sigma_e = \Phi_s\, 3G\,(\lambda - 1) = \Phi_s\, E\,(\lambda - 1)$$
$$\tau_v = \Phi_s\, \eta\dot{\gamma}$$
$$\sigma_v = \Phi_s\, 3\eta\dot{\lambda}$$