Designation: D5992 – 96 (Reapproved 2011)

Standard Guide for Dynamic Testing of Vulcanized Rubber and Rubber-Like Materials Using Vibratory Methods[1]

This standard is issued under the fixed designation D5992; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers dynamic testing of vulcanized rubber and rubber-like (both hereinafter termed "rubber" or "elastomeric") materials and products, leading from the definitions of terms used, through the basic mathematics and symbols, to the measurement of stiffness and damping, and finally through the use of specimen geometry and flexing method, to the measurement of dynamic modulus.

1.2 This guide describes a variety of vibratory methods for determining dynamic properties, presenting them as options, not as requirements. The methods involve free resonant vibration, and forced resonant and nonresonant vibration. In the latter two cases the input is assumed to be sinusoidal.

1.3 While the methods are primarily for the measurement of modulus, a material property, they may in many cases be applied to measurements of the properties of full-scale products.

1.4 The methods described are primarily useful over the range of temperatures from −70°C to +200°C (−100°F to +400°F) and for frequencies from 0.01 to 100 Hz. Not all instruments and methods will accommodate the entire ranges.

1.5 When employed for the measurement of dynamic modulus, the methods are intended for materials having complex moduli in the range from 100 to 100 000 kPa (15 to 15 000 psi) and damping angles from 0 to 90°. Not all instruments and methods will accommodate the entire ranges.

1.6 Both translational and rotational methods are described. To simplify generic descriptions, the terminology of translation is used. The subject matter applies equally to the rotational mode, substituting "torque" and "angular deflection" for "force" and "displacement."

1.7 This guide is divided into sections, some of which include:

1.8 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D945 Test Methods for Rubber Properties in Compression or Shear (Mechanical Oscillograph)

D1566 Terminology Relating to Rubber

2.2 *ISO Document:*[3]

ISO 2856 Elastomers—General Requirements for Dynamic Testing

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[1] This guide is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Testing.

Current edition approved May 1, 2011. Published July 2011. Originally approved in 1996. Last previous edition approved in 2006 as D5992 – 96 (2006)$^{\varepsilon 1}$. DOI: 10.1520/D5992-96R11.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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2.3 *DIN Document:*[4]

DIN 53 513 Determination of viscoelastic properties of elastomers on exposure to forced vibration at non-resonant frequencies

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions— The following terms are listed in related groups rather than alphabetically (see also Terminology D1566).

3.1.2 *delta, δ, n— in the measurement of rubber properties*, the symbol for the phase angle by which the dynamic force leads the dynamic deflection; mathematically true only when the two dynamic waveforms are sine waves (Synonym— *loss angle*).

3.1.3 *tandel, tanδ, n*—mathematical tangent of the phase angle delta (δ); pure numeric; often written spaced: tan del; often written using "delta": tandelta, tan delta (Synonym—*loss factor*).

3.1.4 *phase angle, n*—in general, the angle by which one sine wave leads another; units are either radians or degrees.

3.1.5 *loss angle, n*—synonym for delta (δ).

3.1.6 *loss factor, n*—synonym for tandel (tanδ) (η).

3.1.7 *damping, n*—that property of a material or system that causes it to convert mechanical energy to heat when subjected to deflection; in rubber the property is caused by hysteresis; in some types of systems it is caused by friction or viscous behavior.

3.1.8 *hysteresis, n*—the phenomenon taking place within rubber undergoing strain that causes conversion of mechanical energy to heat, and which, in the "rubbery" region of behavior (as distinct from the glassy or transition regions), produces forces essentially independent of frequency. (See also *hysteretic* and *viscous*.)

3.1.9 *hysteresis loss, n*—per cycle, the amount of mechanical energy converted to heat due to straining; mathematically, the area within the hysteresis loop, having units of the product of force and length.

3.1.10 *hysteresis loop, n*—the Lissajous figure, or closed curve, formed by plotting dynamic force against dynamic deflection for a complete cycle.

3.1.11 *hysteretic, adj— as a modifier of damping*, descriptive of that type of damping in which the damping force is proportional to the amplitude of motion across the damping element.

3.1.12 *viscous, adj—as a modifier of damping*, descriptive of that type of damping in which the damping force is proportional to the velocity of motion across the damping element, so named because of its derivation from an oil-filled dashpot damper.

3.1.13 *equivalent viscous damping, c, n*—at a given frequency, the quotient of $F''(1)$ divided by the velocity of the imposed deflection.

$$c = F''(1)/\omega X^*(1) \qquad (1)$$

3.1.13.1 *Discussion*—The equivalent viscous damping is useful when dealing with equations in many texts on vibration. It is an equivalent only at the frequency for which it is calculated.

3.1.14 *dynamic, adj—in testing*, descriptive of a force or deflection function characterized by an oscillatory or transient condition, as contrasted to a static test.

3.1.15 *dynamic, adj—as a modifier of stiffness or modulus*, descriptive of the property measured in a test employing an oscillatory force or motion, usually sinusoidal.

3.1.16 *static, adj (1)—in testing*, descriptive of a test in which force or deflection is caused to change at a slow constant rate, within or in imitation of tests performed in screw-operated universal test machines.

3.1.17 *static, adj (2)—in testing*, descriptive of a test in which force or deflection is applied and then is truly unchanging over the duration of the test, often as the mean value of a dynamic test condition.

3.1.18 *static, adj (3)—as a modifier of stiffness or modulus*, descriptive of the property measured in a test performed at a slow constant rate.

3.1.19 *stiffness, n*—that property of a specimen that determines the force with which it resists deflection, or the deflection with which it responds to an applied force; may be static or dynamic (See also *complex, elastic, damping*.) (Synonym—*spring rate*).

3.1.20 *modulus, n*—the ratio of stress to strain; that property of a material which, together with the geometry of a specimen, determines the stiffness of the specimen; may be static or dynamic, and if dynamic, is mathematically a vector quantity, the phase of which is determined by the phase of the complex force relative to that of deflection. (See also *complex, elastic, damping*.)

3.1.21 *complex, adj—as a modifier of dynamic force*, descriptive of the total force; denoted by the asterisk (*) as a superscript symbol (F^*); F^* can be resolved into elastic and damping components using the phase of displacement as reference.

3.1.22 *elastic, adj—as a modifier of dynamic force*, descriptive of that component of complex force in phase with dynamic deflection, that does not convert mechanical energy to heat, and that can return energy to an oscillating mass-spring system; denoted by the single prime (') as a superscript symbol, as F'.

3.1.23 *damping, adj—as a modifier of dynamic force*, descriptive of that component of complex force leading dynamic deflection by 90 degrees, and that is responsible for the conversion of mechanical energy to heat; denoted by the double prime (") as a superscript symbol, as F''.

3.1.24 *storage, adj—as a modifier of energy*, descriptive of that component of energy absorbed by a strained elastomer that is not converted to heat and is available for return to the overall

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[4] Available from Beuth Verlag GmbH (DIN-- DIN Deutsches Institut fur Normung e.V.), Burggrafenstrasse 6, 10787, Berlin, Germany, http://www.en.din.de.

mechanical system; by extension, descriptive of that component of modulus or stiffness that is elastic.

3.1.25 *Fourier analysis, n—in mathematics*, analysis of a periodic time varying function that produces an infinite series of sines and cosines consisting of a fundamental and integer harmonics which, if added together, would recreate the original function; named after the French mathematician Joseph Fourier, 1768–1830.

3.1.26 *shear, adj*—descriptive of properties measured using a specimen deformed in shear, for example, shear modulus.

3.1.27 *bonded, adj—in describing a test specimen*, one in which the elastomer to be tested is permanently cemented to members of much higher modulus for two purposes: (*1*) to provide convenient rigid attachment to the test machine, and (*2*) to define known areas for the application of forces to the elastomer.

3.1.28 *unbonded, adj—in describing a test specimen*, one in which the elastomer is molded or cut to shape, but that otherwise demands that forces be applied directly to the elastomer.

3.1.29 *bond area, n—in describing a bonded test specimen*, the cemented area between elastomer and high-modulus attachment member.

3.1.30 *contact area, n— in an unbonded specimen*, that area in contact with a high-modulus fixture, and through which applied forces pass; may or may not be constant, and if lubricated, may deliberately be allowed to change.

3.1.31 *lubricated, adj— in describing an elastomeric test specimen having at least two plane parallel faces and to be tested in compression*, one in which the plane parallel faces are separated from plane parallel platens of the apparatus by a lubricant, thereby eliminating, insofar as possible, friction between the elastomer and platens, permitting the contact surfaces of the specimen to expand in area as the platens are moved closer together.

3.1.32 *Mullins Effect, n*—the phenomenon occurring in vulcanized rubber whereby the second and succeeding hysteresis loops exhibit less area than the first, due to breaking of physical cross-links; may be permanent or temporary, depending on the nature of the material. (See also *preflex effect*.)

3.1.33 *preflex effect, n*—the phenomenon occurring in vulcanized rubber, related to the Mullins effect, whereby the dynamic moduli at low strain amplitude are less after a history to high strains than before. (See also *Mullins effect.*) (Also called strain history effect.)

3.1.34 *undamped natural frequency, n—in a single-degree-of-freedom resonant spring-mass-damper system*, that natural frequency calculated using the following equation:

$$f_n = \text{SQRT}\left(\text{K}'/\text{M}\right) \tag{2}$$

where:

K' = the elastic stiffness of the spring, and
M = the mass.

3.1.35 *transmissibility, n—in the measurement of forced resonant vibration*, the complex quotient of response divided by input; may be absolute or relative.

3.1.36 *absolute, adj—in the measurement of vibration*, a quantity measured relative to the earth as reference.

3.1.37 *relative, adj—in the measurement of vibration*, a quantity measured relative to another body as reference.

3.1.38 *LVDT, n*—abbreviation for "Linear Variable Differential Transformer," a type of displacement transducer characterized by having a primary and two secondary coils arranged along a common axis, the primary being in the center, and a movable magnetic core free to move along the axis that induces a signal proportional to the distance from the center of its travel, and of a polarity determined by the phase of the signals from the two secondary coils. The rotary version is called a Rotary Variable Differential Transformer (RVDT).

3.1.39 *mobility analysis, n*—the science of analysis of mechanical systems employing a vector quantity called "mobility," characteristic of lumped constant mechanical elements (mass, stiffness, damping), and equal in magnitude to the force through the element divided by the velocity across the element.

3.1.40 *impedance analysis, n*—the science of analysis of mechanical systems employing a vector quantity called "impedance," characteristic of lumped constant mechanical elements (mass, stiffness, damping), and equal in magnitude to the velocity across the element divided by the force through the element.

3.1.40.1 *Discussion*—Mobility analysis is sometimes easier to employ than impedance because mechanical circuit diagrams are more intuitively constructed in the mobility system. Either will provide the understanding necessary in analyzing test apparatus.

3.2 *Symbols:*

3.2.1 *General Comments:*

3.2.1.1 Many symbols use parentheses. The (t) denotes a function of time. When enclosing a number, such as (1) or (2), the reference is to the number or "order" of the harmonic obtained through Fourier analysis (see Appendix X2). Thus, all of the parameters indicated as (1) are obtained from the fundamental, or first, harmonic. A second harmonic from the complex force would be denoted as F*(2), etc. It should be noted that each harmonic has a phase angle associated with it. In the case of the fundamental, it is the loss angle (δ). The phase angles become important for the higher harmonics if the reverse Fourier transform is employed to reconstitute data in the time domain.

3.2.1.2 Three superscripts are used: the asterisk (*), the single prime ('), and the double prime ("). This guide discusses dynamic motion and force. As raw data, each is a "complex" parameter, denoted by the asterisk. In this guide force is referenced to motion for its phase. The component of force in phase with motion is denoted by a single prime; the component leading motion by 90 degrees is denoted by the double prime. Quantities deriving from force, such as stress, stiffness, and modulus, like force, are also vector quantities and use the same superscripts to identify their phase relationship.

3.2.1.3 In some literature, the asterisk is omitted from the parameter imposed on the specimen. Thus X*(t) is often