Designation: D150 – 22

Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation[1]

This standard is issued under the fixed designation D150; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These test methods cover the determination of relative permittivity, dissipation factor, loss index, power factor, phase angle, and loss angle of specimens of solid electrical insulating materials when the standards used are lumped impedances. The frequency range addressed extends from less than 1 Hz to several hundred megahertz.

Note 1—In common usage, the word relative is frequently dropped.

1.2 These test methods provide general information on a variety of electrodes, apparatus, and measurement techniques. A reader interested in issues associated with a specific material needs to consult ASTM standards or other documents directly applicable to the material to be tested.[2,3]

1.3 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see 10.2.1.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D374 Test Methods for Thickness of Solid Electrical Insulation (Metric) D0374_D0374M

D618 Practice for Conditioning Plastics for Testing

D1531 Test Methods for Relative Permittivity (Dielectric Constant) and Dissipation Factor by Fluid Displacement Procedures (Withdrawn 2012)[5]

D1711 Terminology Relating to Electrical Insulation

D5032 Practice for Maintaining Constant Relative Humidity by Means of Aqueous Glycerin Solutions

E104 Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions

3. Terminology

3.1 *Definitions:*

3.1.1 Use Terminology D1711 for definitions of terms used in these test methods and associated with electrical insulation materials.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *capacitance, C, n*—that property of a system of conductors and dielectrics which permits the storage of electrically separated charges when potential differences exist between the conductors.

4. Summary of Test Method

4.1 Capacitance and ac resistance measurements are made on a specimen. Relative permittivity is the specimen capacitance divided by a calculated value for the vacuum capacitance (for the same electrode configuration), and is significantly dependent on resolution of error sources. Dissipation factor, generally independent of the specimen geometry, is also calculated from the measured values.

---

[1] These test methods are under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and are the direct responsibility of Subcommittee D09.12 on Electrical Tests.

Current edition approved Sept. 1, 2022. Published October 2022. Originally approved in 1922. Last previous edition approved in 2018 as D150 – 18. DOI: 10.1520/D0150-22.

[2] R. Bartnikas, Chapter 2, "Alternating-Current Loss and Permittivity Measurements," Engineering Dielectrics, Vol. IIB, Electrical Properties of Solid Insulating Materials, Measurement Techniques, R. Bartnikas, Editor, STP 926, ASTM, Philadelphia, 1987.

[3] R. Bartnikas, Chapter 1, "Dielectric Loss in Solids," Engineering Dielectrics, Vol IIA, Electrical Properties of Solid Insulating Materials: Molecular Structure and Electrical Behavior, R. Bartnikas and R. M. Eichorn, Editors, STP 783, ASTM Philadelphia, 1983.

[4] 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.

[5] The last approved version of this historical standard is referenced on www.astm.org.

***A Summary of Changes section appears at the end of this standard**

4.2 This method provides *(1)* guidance for choices of electrodes, apparatus, and measurement approaches; and *(2)* directions on how to avoid or correct for capacitance errors.

4.2.1 General Measurement Considerations:

Fringing and Stray Capacitance
Geometry of Specimens
Edge, Ground, and Gap Corrections
Guarded Electrodes
Calculation of Vacuum Capacitance

4.2.2 Electrode Systems - Contacting Electrodes

Electrode Materials
Conducting Paint
Sprayed Metal
Liquid Metal
Water
Metal Foil
Fired-On Silver
Evaporated Metal
Rigid Metal

4.2.3 Electrode Systems - Non-Contacting Electrodes

Fixed Electrodes
Fluid Displacement Methods
Micrometer Electrodes

4.2.4 Choice of Apparatus and Methods for Measuring Capacitance and AC Loss

Frequency
Two-Terminal Measurements
Fluid Displacement Methods
Direct and Substitution Methods
Three-Terminal Measurements
Accuracy considerations

5. Significance and Use

5.1 *Permittivity*—Insulating materials are used in general in two distinct ways, (*1*) to support and insulate components of an electrical network from each other and from ground, and (*2*) to function as the dielectric of a capacitor. For the first use, it is generally desirable to have the capacitance of the support as small as possible, consistent with acceptable mechanical, chemical, and heat-resisting properties. A low value of permittivity is thus desirable. For the second use, it is desirable to have a high value of permittivity, so that the capacitor is able to be physically as small as possible. Intermediate values of permittivity are sometimes used for grading stresses at the edge or end of a conductor to minimize ac corona. Factors affecting permittivity are discussed in Appendix X3.

5.2 *AC Loss*—For both cases (as electrical insulation and as capacitor dielectric) the ac loss generally needs to be small, both in order to reduce the heating of the material and to minimize its effect on the rest of the network. In high frequency applications, a low value of loss index is particularly desirable, since for a given value of loss index, the dielectric loss increases directly with frequency. In certain dielectric configurations such as are used in terminating bushings and cables for test, an increased loss, usually obtained from increased conductivity, is sometimes introduced to control the voltage gradient. In comparisons of materials having approximately the same permittivity or in the use of any material under such conditions that its permittivity remains essentially constant, it is potentially useful to consider also dissipation factor, power factor, phase angle, or loss angle. Factors affecting ac loss are discussed in Appendix X3.

5.3 *Correlation*—When adequate correlating data are available, dissipation factor or power factor are useful to indicate the characteristics of a material in other respects such as dielectric breakdown, moisture content, degree of cure, and deterioration from any cause. However, it is possible that deterioration due to thermal aging will not affect dissipation factor unless the material is subsequently exposed to moisture. While the initial value of dissipation factor is important, the change in dissipation factor with aging is often much more significant.

5.4 Capacitance is the ratio of a quantity, q, of electricity to a potential difference, V. A capacitance value is always positive. The units are farads when the charge is expressed in coulombs and the potential in volts:

$$C = q/V \qquad (1)$$

5.5 Dissipation factor ((D), (loss tangent), (tan δ)) is the ratio of the loss index (κ") to the relative permittivity (κ') which is equal to the tangent of its loss angle (δ) or the cotangent of its phase angle (θ) (see Fig. 1 and Fig. 2).

$$D = \kappa''/\kappa' \qquad (2)$$

5.5.1 It is calculated via Eq 3:

$$D = \tan\delta = \cot\theta = X_p/R_p = G/\omega C_p = 1/\omega C_p R_p \qquad (3)$$

where:

G = equivalent ac conductance,
X_p = parallel reactance,
R_p = equivalent ac parallel resistance,
C_p = parallel capacitance, and
ω = $2\pi f$ (sinusoidal wave shape assumed).

The reciprocal of the dissipation factor is the quality factor, Q, sometimes called the storage factor. The dissipation factor, D, of the capacitor is the same for both the series and parallel representations as follows:

$$D = \omega R_s C_s = 1/\omega R_p C_p \qquad (4)$$

The relationships between series and parallel components are as follows:

$$C_p = C_s/(1+D^2) \qquad (5)$$

$$R_p/R_s = (1+D^2)/D^2 = 1+(1/D^2) = 1+Q^2 \qquad (6)$$

5.5.2 *Series Representation*—While the parallel representation of an insulating material having a dielectric loss (Fig. 3) is usually the proper representation, it is always possible and occasionally desirable to represent a capacitor at a single frequency by a capacitance, C_s, in series with a resistance, R_s (Fig. 4 and Fig. 2).

5.6 Loss angle ((phase defect angle), (δ)) is the angle whose tangent is the dissipation factor or arctan *κ"/κ'* or whose cotangent is the phase angle.

5.6.1 The relation of phase angle and loss angle is shown in Fig. 1 and Fig. 2. Loss angle is sometimes called the phase defect angle.

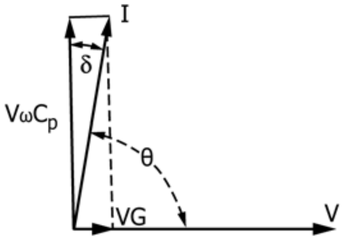

FIG. 1 Vector Diagram for Parallel Circuit

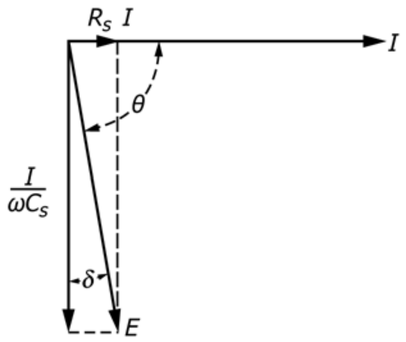

FIG. 2 Vector Diagram for Series Circuit

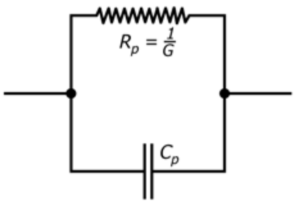

FIG. 3 Parallel Circuit

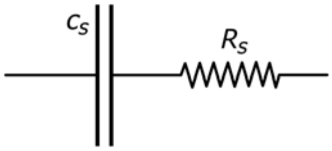

FIG. 4 Series Circuit

5.7 Loss index (κ" (ε$_r$")) is the magnitude of the imaginary part of the relative complex permittivity; it is the product of the relative permittivity and dissipation factor.

5.7.1 The loss index is expressed as:

$$\kappa'' = \kappa' D \quad (7)$$

$$= \text{power loss}/(E^2 \times f \times \text{volume} \times \text{constant})$$

.

When the power loss is in watts, the applied voltage is in volts per centimeter, the frequency is in hertz, the volume is the cubic centimeters to which the voltage is applied, the constant has the value of 5.556×10^{-13}.

NOTE 2—Loss index is the term agreed upon internationally. In the United States, κ" was formerly called the loss factor.

5.8 Phase angle (θ) is the angle whose cotangent is the dissipation factor, arccot κ"/κ' and is also the angular difference in the phase between the sinusoidal alternating voltage applied to a dielectric and the component of the resulting current having the same frequency as the voltage.

5.8.1 The relation of phase angle and loss angle is shown in Fig. 1 and Fig. 2. Loss angle is sometimes called the phase defect angle.

5.9 Power factor (*PF*) is the ratio of the power in watts, *W*, dissipated in a material to the product of the effective sinusoidal voltage, *V*, and current, *I*, in volt-amperes.

5.9.1 Power factor is expressed as the cosine of the phase angle θ (or the sine of the loss angle δ).

$$PF = W/VI = G/\sqrt{G^2 + (\omega C_p)^2} = \sin\delta = \cos\theta \quad (8)$$

When the dissipation factor is less than 0.1, the power factor differs from the dissipation factor by less than 0.5 %. Their exact relationship is found from the following:

$$PF = D/\sqrt{1 + D^2} \quad (9)$$

$$D = PF/\sqrt{1 - (PF)^2}$$

5.10 Relative permittivity ((relative dielectric constant) (SIC) κ'(ε$_r$)) is the real part of the relative complex permittivity. It is also the ratio of the equivalent parallel capacitance, C_p, of a given configuration of electrodes with a material as a dielectric to the capacitance, C_v, of the same configuration of electrodes with vacuum (or air for most practical purposes) as the dielectric:

$$\kappa' = C_p/C_v \quad (10)$$

NOTE 3—In common usage the word "relative" is frequently dropped.

NOTE 4—Experimentally, vacuum must be replaced by the material at all points where it makes a significant change in capacitance. The equivalent circuit of the dielectric is assumed to consist of C_p, a capacitance in parallel with conductance. (See Fig. 3.)

NOTE 5—C_x is taken to be C_p, the equivalent parallel capacitance as shown in Fig. 3.

NOTE 6—The series capacitance is larger than the parallel capacitance by less than 1 % for a dissipation factor of 0.1, and by less than 0.1 % for a dissipation factor of 0.03. If a measuring circuit yields results in terms of series components, the parallel capacitance must be calculated from Eq 5 before the corrections and permittivity are calculated.

NOTE 7—The permittivity of dry air at 23 °C and standard pressure at 101.3 kPa is 1.000536 (**1**).[6] Its divergence from unity, κ' – 1, is inversely proportional to absolute temperature and directly proportional to atmospheric pressure. The increase in permittivity when the space is saturated with water vapor at 23 °C is 0.00025 (**2, 3**), and varies approximately linearly with temperature expressed in degrees Celsius, from 10 °C to 27 °C. For partial saturation the increase is proportional to the relative humidity.

6. General Measurement Considerations

6.1 *Fringing and Stray Capacitance*—These test methods are based upon measuring the specimen capacitance between electrodes, and measuring or calculating the vacuum capacitance (or air capacitance for most practical purposes) in the same electrode system. For unguarded two-electrode measurements, the determination of these two values required to compute the permittivity, κ$_x$' is complicated by the presence of undesired fringing and stray capacitances which get included in the measurement readings. Fringing and stray capacitances are illustrated by Figs. 5 and 6 for the case of two unguarded parallel plate electrodes between which the specimen is to be placed for measurement. In addition to the desired direct interelectrode capacitance, C$_v$, the system as seen at terminals a-a' includes the following:

---

[6] The boldface numbers in parentheses refer to the list of references appended to these test methods.