Designation: ~~D3382 – 13~~ D3382 – 22

Standard Test Methods for
Measurement of Energy and Integrated Charge Transfer Due to Partial Discharges (Corona) Using Bridge Techniques[1]

This standard is issued under the fixed designation D3382; 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 These test methods cover two bridge techniques for measuring the energy and integrated charge of pulse and pseudoglow partial discharges:

1.2 Test Method A makes use of capacitance and loss characteristics such as measured by the transformer ratio-arm bridge or the high-voltage Schering bridge (Test Methods D150). Test Method A ~~can be used~~ has been found useful to obtain the integrated charge transfer and energy loss due to partial discharges in a dielectric from the measured increase in capacitance and tan δ with voltage. (See also IEEE 286 and IEEE 1434)

1.3 Test Method B makes use of a somewhat different bridge circuit, identified as a charge-voltage-trace (parallelogram) technique, which indicates directly on an oscilloscope the integrated charge transfer and the magnitude of the energy loss due to partial discharges.

1.4 Both test methods are intended to supplement the measurement and detection of pulse-type partial discharges as covered by Test Method D1868, by measuring the sum of both pulse and pseudoglow discharges per cycle in terms of their charge and energy.

1.5 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.* Specific precaution statements are given in Section 7.

1.6 *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:*[2]
D150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation
D1711 Terminology Relating to Electrical Insulation
D1868 Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems

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

2.2 *IEEE Documents*[3]

IEEE 286 Recommended Practice for Measurement of Power Factor and Power Factor Tip-up for Rotating Machine Stator Coil Insulation

IEEE 1434 Guide to the Measurement of Partial Discharges in Rotating Machinery

IEEE C57.113 Guide for PD Measurements in Liquid-Filled Power Transformers

IEEE Standard C57.124 Recommended Practice for the Detection of PD and the Measurement of Apparent Charge in Dry-Type Transformers

2.3 *AEIC Documents*[4]

AEIC T-24-380 Guide for Partial Discharge Procedure

AEIC CS5-87 Specifications for Thermoplastic and Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 through 35 kV, 9th Edition, 1987

3. Terminology

3.1 *Definitions:*

3.1.1 *pseudoglow discharge, n*—a type of partial discharge, which takes place within an expanded discharge channel and is characterized by pulses of relatively low magnitude and long rise time.

3.1.1.1 *Discussion*—
Pseudoglow discharges occur within a diffused discharge channel, whose emitted glow fills the entire intervening gap or cavity space (**1**).[5] The discharge rate behavior as a function of applied voltage is similar to that of the rapid rise time pulse (spark-type) discharges. The successive pseudoglow discharge pulses occur over the first quadrant of each half cycle and in some gases, notably helium, their magnitude is found to diminish to zero. At this point, a transition to a pulseless glow discharge ~~can occur.~~ has been observed. Its occurrence, which is manifest by distortion in the sinusoidal voltage wave, is rare. At discharge inception of a single cavity, the pattern of pseudoglow discharges consists of a single long rise time discharge current pulse in each half-cycle. It has become common practice to refer to this particular type of pattern as that of a glow discharge.

Pseudoglow partial discharges, which occur at low gas pressures, such as in insulating systems of electrical equipment for aerospace applications, have unduly long rise times and a frequency spectrum that falls bellow the bandwidth of conventional partial discharge pulse detectors (**2**). As a consequence, ~~they cannot be detected by~~ the partial discharge detectors specified in Test Method D1868 ~~; however they can be detected and measured by either Method~~ are not suitable for this purpose; however Methods A or B of Test Methods D3382~~.~~ have been found suitable for use.

3.1.2 *pulse discharge, n*—a type of partial-discharge phenomenon characterized by a spark-type breakdown which occurs in a narrow constricted channel.

3.1.2.1 *Discussion*—
The resultant detected pulse discharge has a short rise time and its Fourier frequency spectrum ~~may~~ has been observed at times to extend as far as 1 GHz. Such a pulse discharge ~~may be~~ has been readily detected on occasion by conventional pulse detectors, that are generally designed for partial-discharge measurements within the frequency band from 30 kHz to several megahertz. (See also IEEE 1434, IEEE C57.113, IEEE C57.124, AEIC T-24-380, and AEIC CS5-87.)

3.1.3 *pulseless-glow discharge, n*—an uncommon type of partial discharge , whose existence is manifest not by the usual abrupt voltage fall discontinuities in the sinusoidal voltage wave at each discharge epoch but rather by distortions in the waveform.

3.1.3.1 *Discussion*—
It is generally found that the pulseless glow region develops only when preceded by a pseudoglow discharge in which the abrupt voltage collapse magnitudes at each discharge have gradually diminished in the limit to zero. The nature of this pulseless glow region is not fully understood, but it is believed to consist of a very weakly ionized gas volume. Further increases in the applied voltage ~~can~~ have been found to potentially lead to more complex partial discharge patterns, consisting of regions of pseudoglow, pulseless and pulse type discharges (**3**). Pulse type partial discharge detectors of the type described in Test Method D1868 ~~cannot be employed~~ are not suitable to detect pulseless glow discharges.

3.1.4 See (**1**) and (**3**) for more information on the previous definitions.

3.1.5 For definitions of other terms pertaining to this standard refer to Terminology D1711.

3.2 *Symbols:*

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[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.

3.2.1 Refer to Annex A1 for symbols for mathematical terms used in this standard.

4. Summary of Test Methods

4.1 It is possible to represent the dielectric characteristics of a specimen of solid insulating material by a parallel combination of capacitance and conductance. The values of capacitance and conductance remain practically constant over the useful range of alternating voltage stress at a fixed frequency. If, however, the specimen contains gaseous inclusions (cavities), incremental increases in capacitance and conductance occur as the voltage stress is raised above the value necessary to initiate partial discharges in the cavities. The energy loss in the incremental conductance is considered to be that dissipated by the partial discharges.

4.2 In Test Method A an initial measurement is made of the capacitance and loss characteristic of the specimen at an applied voltage below the discharge inception level. The voltage is then raised to the specified test value and a second measurement made. The energy loss due to partial discharges is calculated from the results of the two measurements.

4.3 In Test Method B a special bridge circuit is balanced at a voltage below the discharge inception level. The voltage is then raised to the specified test value, but the bridge is not rebalanced. Any unbalanced voltage at the detector terminals is displayed in conjunction with the test voltage on an oscilloscope. The oscilloscope pattern approximates a parallelogram, the area of which is a measure of the energy loss due to partial discharges.

5. Significance and Use

5.1 These test methods are useful in research and quality control for evaluating insulating materials and systems since they provide for the measurement of charge transfer and energy loss due to partial discharges(**4**) (**5**) (**6**).

5.2 Pulse measurements of partial discharges indicate the magnitude of individual discharges. However, if there are numerous discharges per cycle it is occasionally important to know their charge sum, since this sum ~~can be~~ is related to the total volume of internal gas spaces that are discharging, if it is assumed that the gas cavities are simple capacitances in series with the capacitances of the solid dielectrics (**7**) (**8**).

5.3 Internal (cavity-type) discharges are mainly of the pulse (spark-type) with rapid rise times or the pseudoglow-type with long rise times, depending upon the discharge governing parameters existing within the cavity. If the rise times of the pseudoglow discharges are too long, they will evade detection by pulse detectors as covered in Test Method D1868. However, both the pseudoglow discharges irrespective of the length of their rise time as well as pulseless glow ~~can be~~ are readily measured either by Method A or B of Test Methods D3382.

5.4 Pseudoglow discharges have been observed to occur in air, particularly when a partially conducting surface is involved. It is possible that such partially conducting surfaces will develop with polymers that are exposed to partial discharges for sufficiently long periods to accumulate acidic degradation products. Also in some applications, like turbogenerators, where a low molecular weight gas such as hydrogen is used as a coolant, it is possible that pseudoglow discharges will develop.

6. Sources of Errors

6.1 *Surface Discharges*—All discharges in the test specimen are measured, whether on the surface or in internal cavities. If it is desired to measure only internal cavities, the other discharges must be avoided. In the case of an insulated conductor with an outer electrode on the surface (such as a cable or generator coil), it has been found useful to use a closely-spaced guard ring connected to ground to remove the surface discharges at the end of this outer electrode ~~can be removed from the measurement with a closely-spaced guard ring connected to ground.~~ from the measurement. See Section 4 of Test Methods D150.

6.2 Since tests will be made at ionizing voltage, all connections making up the complete high-voltage circuit ~~should~~shall be free of corona to avoid measurement interference. See Section 5 of Test Method D1868.

6.3 Anomalous changes in insulation losses with changes in voltage stress ~~can~~ have been observed to occur as a result of phenomena other than partial discharges. Such losses are a source of error in these methods, since they are indistinguishable from discharge losses. However, these losses are often negligible in comparison with partial discharge losses.

6.4 It is possible that any temperature change in the specimen between the times at which the low-voltage and high-voltage measurements are taken will cause a change in the normal losses and appear as changes in discharge energy, thus causing an error in test results. This situation ~~can be~~ is recognized ~~in~~by Method B and corrective action taken (see 11.3).

6.5 Paint used to grade potential on the surface of some insulation specimens (for example, generator stator coil) shall not be included in the measurement, since it is possible that the conductance of such paints will change with voltage and affect the accuracy of the method as a measure of discharge energy. It is sometimes possible to exclude the painted surfaces from the measuring circuit by the use of guarding or shielding techniques.

7. Hazards

7.1 **Warning**— *It is possible that lethal voltages will be present during this test. It is essential that the test apparatus, and all associated equipment potentially electrically connected to it, be properly designed and installed for safe operation. Solidly ground all electrically conductive parts that any person might come in contact with during the test. Provide means for use at the completion of any test to ground any parts which: were at high voltage during the test; have the potential to have acquired an induced charge during the test; have the potential to retain a charge even after disconnection of the voltage source. Thoroughly instruct all operators in the proper way to conduct tests safely. When making high voltage tests, particularly in compressed gas or in oil, it is possible that the energy released at breakdown will be sufficient to result in fire, explosion, or rupture of the test chamber. Design of test equipment, test chambers, and test specimens shall be such as to minimize the possibility of such occurrences and to eliminate the possibility of personal injury.*

7.2 **Warning**— *Ozone is a physiologically hazardous gas at elevated concentrations. The exposure limits are set by governmental agencies and are usually based upon recommendations made by the American Conference of Governmental Industrial Hygienists.*[6] Ozone is likely to be present whenever voltages exist which are sufficient to cause partial, or complete, discharges in air or other atmospheres that contain oxygen. Ozone has a distinctive odor which is initially discernible at low concentrations but sustained inhalation of ozone can cause temporary loss of sensitivity to the scent of ozone. Because of this it is important to measure the concentration of ozone in the atmosphere, using commercially available monitoring devices, whenever the odor of ozone is persistently present or when ozone generating conditions continue. Use appropriate means, such as exhaust vents, to reduce ozone concentrations to acceptable levels in working areas.

TEST METHOD A

8. Procedure

8.1 Conventional circuits for the measurement of alternating-voltage capacitance and loss characteristics of insulation ~~can be used~~ are appropriate for this method. The transformer-ratioarm bridge shown in Fig. 1, or the Schering bridge shown in Fig. X4.2 of Test Methods D150 are well suited to this application.

8.2 Energize the test specimen at a low voltage, V_1, below the discharge-inception voltage, and measure capacitance C_{x1} and dissipation factor $\tan \delta_1$. Raise the voltage to a specified test level, V_2, and repeat the measurements for C_{x2} and $\tan \delta_2$. Calculate the power loss, ΔP, in watts due to discharges at voltage V_2 as follows:

$$\Delta P = \omega V_2^2 (C_{x2} \ \tan \ \delta_2 - C_{x1} \ \tan \ \delta_1) \tag{1}$$

$$= P_2 - (P_1 V_2^2 / V_1^2) \tag{2}$$

8.3 The increment of dissipation factor $\tan \delta_2 - \tan \delta_1$, called delta tan delta, and written $\Delta \tan \delta$, is often used as an index of discharge intensity.

$$C_X = \frac{C_S W_2}{W_1}$$

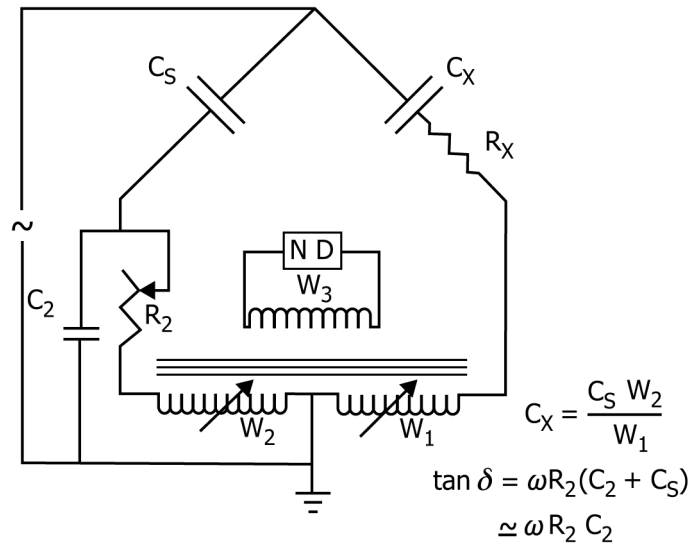$$\tan \delta = \omega R_2 (C_2 + C_S)$$

$$\simeq \omega R_2 C_2$$

FIG. 1 Typical Transformer-Ratio-Arm Bridge (Method A)

9. Precision and Bias

9.1 This test method has been in use for many years, but no statement for precision has been made and no activity is planned to develop such a statement.

9.2 A statement of bias is not possible due to the lack of a standard reference material.

10. Interferences

10.1 *Harmonics*—The test voltage must be reasonably free of harmonics in order to produce the required horizontal line below the inception voltage. Harmonics will produce a wavy rather than a flat line. If the waviness is too severe, the voltage source will have to be filtered to remove the harmonics. The removal of harmonics is more important when the quantities to be measured are small.

TEST METHOD B

11. Procedure

11.1 The test method requires the placing of the test specimen, considered essentially as a high-voltage capacitor, in series with a low-voltage capacitor, across a sinusoidal test-voltage source. See Fig. 2. Two other bridge arms provide a voltage for balancing, at an applied voltage level below inception of partial discharges, the sinusoidal voltage across the low-voltage capacitor. Any partial discharges that occur at higher applied voltages in the specimen will be integrated by the low-voltage capacitor to produce an unbalanced voltage. The unbalanced voltage controls the vertical deflection of an oscilloscope beam, while a voltage proportional to, and in phase with the test voltage, controls the horizontal deflection. A description of a suitable circuit for this test method is detailed in Annex A2.

11.2 The oscilloscope display is simply a horizontal line below the discharge inception voltage where no unbalanced voltages occur. Above the discharge inception voltage the display opens into an approximate parallelogram. The height of the parallelogram represents the sum of the partial discharges per half cycle, and the area represents the energy dissipated per cycle by the discharges. See Fig. 3.

11.3 If the parallelogram has been tilted or distorted by the increase in voltage, a small adjustment in the capacitance and resistance balance ~~can~~shall be made to make the top and bottom of the parallelogram horizontal. This will compensate for some changes in capacitance and tan δ due to effects other than partial discharges.
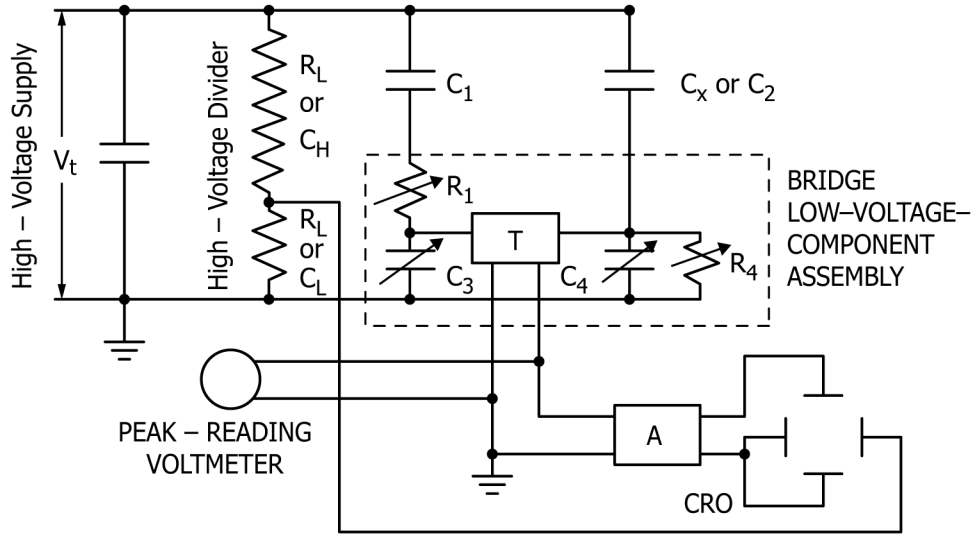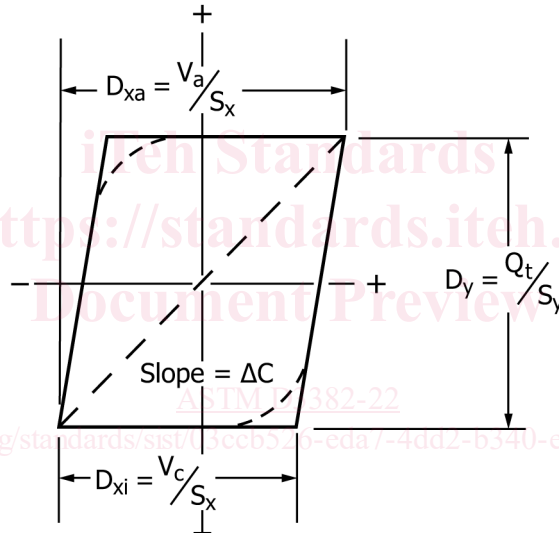
FIG. 2 Typical Charge-Voltage-Trace Bridge (Method B)

V_c	=	discharge inception voltage peak to peak
V_a	=	applied voltage peak to peak
$D_y S_y$	=	Q_t coulombs per half cycle
$S_y S_x A$	=	W joules per cycle
A	=	area = $D_{xi} D_y$
ΔC	=	slope = $C_x' - C_x = D_y S_y / D_{xa} S_x$

FIG. 3 Idealized Loop Trace (Method B)

12. Calibration of Oscilloscope Coefficients

12.1 In order to evaluate the parallelogram, it is necessary to determine the deflection sensitivities of the oscilloscope. See Fig. 3. The horizontal-deflection sensitivity, S_x, in volts per centimetre, is found from observing the horizontal deflection, D_{xi} or D_{xa}, in centimetres, to a test voltage having a peak-to-peak value of V_c or V_a as measured by accurate independent means.

$$S_x = V_c/D_{xi} = V_a/D_{xa} \tag{3}$$

12.2 Assess the vertical-deflection sensitivity, S_y, in coulombs per centimetre, by observing the vertical deflection, D_y, in centimetres, to a known charge, Q_c, in coulombs, by a square-wave generator having a peak-to-peak voltage, E_c, coupled to the low-voltage capacitor through a calibrating capacitor, C_c, of a much smaller value. The square-wave frequency needs to be of the same order as the test frequency.

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$$S_y = Q_c/D_y = E_c C_c/D_y \tag{4}$$

12.3 Alternatively, determine Q_t, in coulombs, from the turns ratio, n, of the detector transformer, T, and the voltage, V_p, required at the vertical input of the oscilloscope to produce a vertical deflection of the same magnitude as that produced by the discharges. Measure V_p directly by connecting a peak-to-peak voltmeter across the vertical input of the oscilloscope as shown in Fig. 2, and read when the parallelogram is obtained. Then:

$$Q_t = nV_p C_4 \tag{5}$$

where Q_t is the total charge per half cycle, or

$$S_y = nV_p C_4/D_y \tag{6}$$

where D_y is the height of the parallelogram in centimetres.

13. Calculation

13.1 *Integrated Charge*—The integrated-charge transfer per half cycle, Q_t, is the product of the vertical deflection, D_y, of the oscilloscope (the height of the parallelogram) multiplied by the vertical-deflection sensitivity S_y:

$$Q_t = D_y S_y \tag{7}$$

13.2 *Energy*—The energy, W, in joules per cycle, is the area, A, of the parallelogram measured in the same units as the deflection sensitivities:

$$W = A S_x S_y \tag{8}$$

Where the parallelogram is well defined, the area is the product of the parallelogram heights, D_y, and the width, D_{xi}, conveniently measured along the center axis of the oscilloscope raster. Thus

$$W = D_{xi} D_y S_x S_y \tag{9}$$

13.3 *Capacitance Increase*—The increase, ΔC, of the specimen capacitance with voltage, from the voltage below the discharge inception, where the bridge is initially balanced, up to the test voltage is:

$$\Delta C = Q_t/V_a \tag{10}$$

where V_a is the applied peak-to-peak voltage at which the test is being made. This voltage corresponds to the total horizontal projected width of the parallelogram.

13.4 For further analysis of measurements see Annex A3.

14. Report

14.1 Report the following information:

14.1.1 *Identification*—Include information that describes the specimen, so as to permit comparison between similar systems or different production lots of the same system, and to permit other types of comparison between different materials,

14.1.2 *Test Method*—Include a description of the test procedure, test apparatus, test specimen, the test voltages and length of time applied, preconditioning and history, and ambient conditions and any other factors that has the potential to influence the performance of the test and the result obtained, and that will permit exact duplication of the tests at a later time,

14.1.3 Date of test,

14.1.4 Where tests were performed and by whom,

14.1.5 *Test Results*—Include experimental values obtained, number of specimens tested, along with results from appropriate calculations such as average (mean), standard deviation, etc., and

14.1.6 *Observations*—Include information of importance to the understanding or interpretation of the test method and results that have not been included in the foregoing sections.