Designation: D2275 – 14

Standard Test Method for Voltage Endurance of Solid Electrical Insulating Materials Subjected to Partial Discharges (Corona) on the Surface[1]

This standard is issued under the fixed designation D2275; 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 test method determines the voltage endurance of solid electrical insulating materials for use at commercial power frequencies under the action of corona (see Note 1). This test method is more meaningful for rating materials with respect to their resistance to prolonged ac stress under corona conditions for comparative evaluation between materials.

NOTE 1—The term "corona" is used almost exclusively in this test method instead of "partial discharge," because it is a visible glow at the edge of the electrode interface that is the result of partial discharge. Corona, as defined in Terminology D1711, is "visible partial discharges in gases adjacent to a conductor."

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

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 and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D149 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies

D618 Practice for Conditioning Plastics for Testing

D1711 Terminology Relating to Electrical Insulation

D1868 Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems

D3382 Test Methods for Measurement of Energy and Integrated Charge Transfer Due to Partial Discharges (Corona) Using Bridge Techniques

2.2 *Special Technical Publications:*

Symposium on Corona, STP 198, ASTM, 1956[2]

Corona Measurement and Interpretation, Engineering Dielectrics, Vol 1, STP 669, ASTM, 1979[2]

2.3 *International Electrotechnical Commission (IEC) Documents:*

IEC Publication 60343 Recommended Test Methods for Determining the Relative Resistance of Insulating Materials to Breakdown by Surface Discharges[3]

2.4 *Institute of Electrical and Electronic Engineers (IEEE) Document:*

IEEE 930-1987 Guide for the Statistical Analysis of Electrical Insulation Voltage Endurance Data[4]

3. Terminology

3.1 *Definitions*—For definitions of other terms used in this standard, refer to Terminology D1711 and Test Method D1868.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *surface corona, n*—corona that exists in the electrically stressed gas where electrodes are near insulation surfaces.

3.2.2 *threshold voltage*—that voltage below which failure will not occur under the test conditions irrespective of the duration of the test.

3.2.3 *voltage endurance, n*—the time that an insulating material can withstand a prolonged alternating voltage stress under the action of surface corona.

3.2.4 *voltage stress-time curve, n*—a plot of the logarithm of the mean or median time to failure of a material against voltage stress (or the logarithm of voltage stress) for a particular set of test conditions.

3.2.4.1 *Discussion*—The plot is the quantitative depiction of the voltage stress endurance over a range of voltage stress for the conditions of test, and for the thickness tested. The curves of a material obtained at two thicknesses are different.

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[1] This test method is under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.12 on Electrical Tests.

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[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.

[4] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331, http://www.ieee.org.

3.2.5 *volt-time curve, n*—a plot of the logarithm of the mean or median time to failure of a material against voltage (or the logarithm of voltage) for a particular set of test conditions.

3.2.5.1 *Discussion*—The plot is the quantitative depiction of the voltage endurance over a range of voltage for the conditions of the test, which includes the particular thickness tested.

4. Summary of Test Method

4.1 In this test method, voltage sufficient to produce surface corona is applied to nine samples from the same specimen until failure occurs. The voltage endurance is the relative time to failure, determined by the voltage-time curve or Weibull Probability Plot.

4.2 When there is a large dispersion of times to failure for a given sample, it is acceptable to use the median time of nine specimens (time of fifth failure) as the failure time for the sample. This removes the necessity of waiting for the last few to fail. The mean can also be determined statistically (see IEEE 930-1987 for additional information).

4.3 Under the conditions outlined in Appendix X2 it is permissible for the test to be accelerated by increasing the frequency of the applied voltage. In cases agreed upon between the buyer and the seller, or required in relevant specifications to perform testing on specific specimens where a service condition is thought to alter the corona endurance, this factor shall be introduced as part of the test and reported.

4.4 It is possible to obtain additional information from the test if corona-voltage levels and corona intensity are measured at the start of the test and monitored at various stages of deterioration of the insulation. The voltage levels include corona-inception voltage, corona-extinction voltage, and corona intensity using Test Method D1868.

NOTE 2—Comparative measurements of corona power or energy by bridge and oscilloscope techniques can also be informative.

5. Significance and Use

5.1 This test method is useful in research and quality control for evaluating insulating materials and systems since they provide for the measurement of the endurance used to compare different materials to the action of corona on the external surfaces. A poor result on this test does not indicate that the material is a poor selection for use at high voltage or at high voltage stress in the absence of surface corona; surface corona is not the same as corona that occurs in internal cavities. (See Test Methods D3382.)

5.2 This test method is also useful for comparison between materials of the same relative thickness. When agreed upon between the buyer and the seller, it is acceptable to express any differences in terms of relative time to failure or the magnitude of voltage stress (kV/mm or kV/in.) required to produce failure in a specified number of hours.

5.3 It is possible for this test method to also be used to examine the effects of different processing parameters on the same insulating material, such as residual strains produced by quenching, high levels of crystallinity or molding processes that control the concentration and sizes of gas-filled cavities.

5.4 The data are generated in the form of a set of values of lifetimes at a voltage. The dispersion of failure times is analyzed using one of the methods below:

5.4.1 Weibull Probability Plot.

5.4.2 Statistically (see IEEE 930-1987 for additional information), to yield an estimate of the central value of the distribution and its standard deviation.

5.4.3 Truncating a test at the time of the fifth failure of a set of nine and using that time as the measure of the central tendency. Two such techniques are described in 10.2.

5.5 This test method intensifies some of the more commonly met conditions of corona attack so that materials are able to be evaluated in a time that is relatively short compared to the life of the equipment. As with most accelerated life tests, caution is necessary in extrapolation from the indicated life to actual life under various operating conditions in the field.

5.6 The possible factors related to failures produced by corona are:

5.6.1 Corona eroding the insulation until the remaining insulation can no longer withstand the applied voltage.

5.6.2 Corona causing the insulation surface to become conducting due to carbonization, so that failure occurs quickly.

5.6.3 Forming of compounds such as oxalic acid crystals causing the surface conductance to vary with ambient humidity. It is possible conductance will be at a sufficient level to reduce the potential gradient at the electrode edge at moderate humidities, and thus cause either a reduction in the amount of corona, or its cessation, thus retarding failure.

5.6.4 Corona causing "treeing" within the insulation and consequently accelerating the time to failure.

5.6.5 Gases released within the insulation that change its physical dimensions.

5.6.6 Changes in the physical properties of an insulating material; embrittlement or cracking, for instance, causing the material to lose flexibility or crack, or both, and thus make it useless.

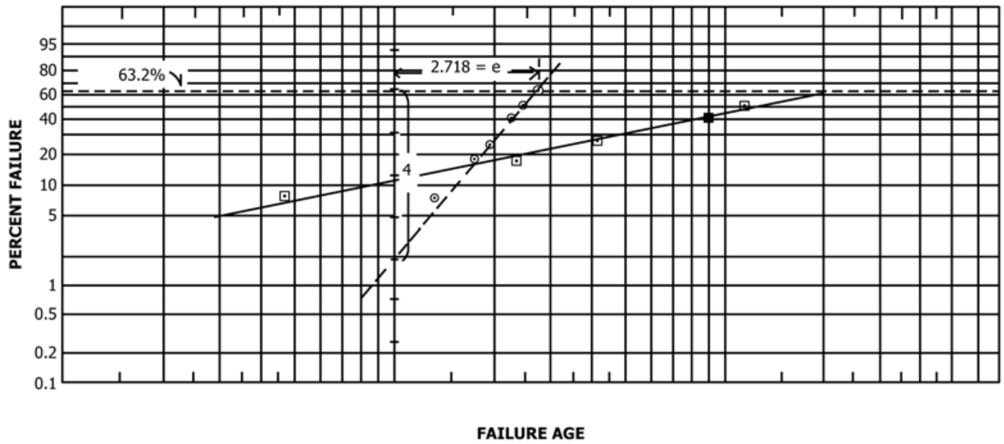
5.7 Tests are often made in open air, at 50 % relative humidity. In cases agreed upon between the buyer and the seller, additional information can be obtained for some materials with tests in circulating air at 20 % relative humidity or less (see Appendix X1).

5.7.1 If tests are made in an enclosure, the restriction in the flow of air can trap ozone and influence the results (see Appendix X2).

5.7.2 When tests are done outside the standard conditions, the report shall note the deviation and the alternative conditions.

5.8 The variability of the time to failure is a function of the consistency of the test parameters, such as voltage levels, which shall be monitored. The Weibull slope factor, β, is recommended as a measure of variability. β is the slope obtained when percent failure is plotted against failure time on Weibull probability paper. Such a plot is called a Weibull Probability Plot (see Fig. 1).

5.9 The shape of the Weibull Probability Plot can provide additional information. It is possible that a non-straight-line plot will indicate more than one mechanism of failure. For



NOTE 1—Plotting percentage are 100 times the average of (n – ½)/N and n/(N + 1). Artificial data were placed on a line (dashed) drawn to illustrate a Weibull line with a β of 4. A second line (not dashed) illustrates the distribution of failure times which are characteristic of materials with very flat volt-time curves, such as mica composites. This line has a β value of 0.7.

FIG. 1 Representative Weibull Plot Showing the First Five Failures of a Group Specimen of Nine.

instance, a few unaccountably short time failures in the set indicating a small portion of defective specimens with a different failure mechanism from the rest of the lot.

6. Apparatus

6.1 *Electrical Circuit:*

6.1.1 *High-Voltage Supply*—A high-voltage source with controls and voltage-measuring means in accordance with requirements of Test Method D149; which in addition provides a test voltage stable within ±1 % during the test period. If necessary use a voltage stabilizer, or other suitable equipment, for this purpose.

6.1.2 It is essential to provide for safe, continuous, and reliable operation, with automatic detection of failure times and automatic removal of specimens from the test circuit when they fail. Two suitable circuits are described in detail in Appendix X3. Particular features are described as follows:

6.1.2.1 *Current Limiting Resistors*—A series of resistors in the high voltage line between the transformer and the specimen limit the current to approximately 0.05 A when a specimen fails. These resistors must have adequate voltage rating. The current limitation prevents pitting of the electrodes and minimizes surges. Since accidental grounding of the high voltage electrode will cause the resistors to become extremely hot, it is important to assure that the current goes through the interruption circuit.

6.1.2.2 *Specimen Circuit Opening*—An additional resistor of 50 kΩ (±10 %) in series with each specimen develops a sufficient voltage across it, when a specimen fails, to operate a special high-voltage fuse system that opens a gap in series with the specimen when it fails (see Fig. X3.2). This allows the other specimens to continue on test. The failure current simultaneously operates a relay which provides a pulse of current to operate a recorder such as a recording ammeter, an event recorder, or a running time meter to indicate the time to failure. (See Fig. X3.1, for instance.)

6.1.2.3 An alternative technique has advantages for lower voltages associated with thin films and with materials of relatively low dielectric strength. In such cases, the possibility exists that the failure current will not be high enough to melt fuse wire. It also works better than the fuse wire at higher voltages where intense discharge currents flow sporadically, making the fuse wire scheme unreliable. Fig. X3.3 shows a relay-latch mechanism that has been successfully used. Specimen failure current energizes the coil of relay *LM5*, closes the contacts, energizes the coil of the latching relay, and releases the latch, which opens the contacts in the specimen circuit. The latch contacts are designed to open with sufficient clearance to interrupt the high-voltage arc. Auxiliary contacts of relay *LM5* cause the event recorder to indicate the time of failure. The remaining specimens remain under continuous test automatically with no time lost and no need for extra attention by personnel.

6.1.2.4 *Circuit Protection*—An automatic circuit breaking device protects the entire circuit by opening when 0.05 A of secondary current is drawn for more than 15 s. (See Fig. X3.1, for instance.)

6.2 It is imperative to electrically interlock the test chamber, and:

6.2.1 A grounded metal base is recommended to be installed under the specimens and under any high voltage bus structure, so that any free lead will contact ground and operate the breaker (see 7.2).

6.2.2 An isolation transformer with a grounded shield to provide power to relay circuits, and event recorders (see 7.2).

6.2.3 A smoke detector in the roof of the chamber (see 7.1).

6.2.4 A means of test chamber ventilation (see 7.3 and 7.4).

6.2.5 Equipment for control of ambient conditions (see Appendix X1).

6.3 *Electrodes:*

6.3.1 The upper electrodes shall be:

6.3.1.1 *Cylinders,* 12.7 mm (½ in.) in diameter, 13 mm high, with edges rounded to a radius of 1.6 mm (0.0625 in.), loaded to give a total weight of at least 90 g, and made self-aligning to conform to the surface of the specimen, or

6.3.1.2 *Steel Spheres,* 12.7 mm (½ in.) in diameter, loaded to give a total weight of at least 50 g. The steel balls used in ball bearings make satisfactory electrodes, or

6.3.1.3 *Cylinders,* 6.0 ± 0.3 mm (¼ in.) in diameter, with edges rounded to a radius of 1 mm (0.04 in.) and weight of approximately 30 g, and made self-aligning to conform to the surface of the specimen. This is the IEC standard electrode.

6.3.2 The lower electrodes shall extend beyond the upper electrodes by a minimum 12.7 mm (½ in.) and so that the lower electrode centers are separated by at least 51 mm (2.0 in.). The simplest design is to make the lower electrode one common plate, if that meets the needs of the electrical circuit.

6.3.3 The standard electrode material is stainless steel Type 309 or 310. The surface finish shall be 0.4 µm (16 µin.).

6.4 The test chamber provides for control of the ambient conditions by supplying a constant flow of a chosen atmosphere, or by preventing flow if that is desired. When flow is desired, there are two acceptable methods to introduce the atmosphere: by controlled draft (as in a hood in a controlled atmosphere laboratory), or by means of a manifold directing the flow to nozzles which terminate at a distance of 13 ± 1 mm from the edge of the top electrode of the specimen. The chamber must be connected to a vent to remove ozone and other gasses (see also 9.1 and Appendix X1).

7. Hazards

7.1 **Warning—**Provide adequate protection against fire. Avoid the use of panels and enclosures made of flammable materials such as transparent plastics. Electrical design features related to this risk are given in 6.2.1 and 6.4.

7.2 **Warning—**Lethal voltages are present during this test. It is essential that the test apparatus, and all associated equipment electrically connected to it, be properly designed and installed for safe operation.

7.2.1 *Solidly ground all electrically conductive parts that any person might come in contact with during the test.*

7.2.2 *At the completion of any test, provide means to ground any parts which possibly acquired an induced charge during the test and retained even after disconnection of the voltage source.*

7.2.3 *Thoroughly instruct all operators in the proper way to conduct the test safely. When making high voltage tests, particularly in compressed gas or in oil, the energy released at breakdown has the potential to be sufficient enough to result in fire, explosion, or rupture of the test chamber. Design test equipment, test chambers, and test specimens so as to minimize the possibility of such occurrences and to eliminate the possibility of personal injury.*

7.3 **Warning—**The tests of this test method generate ozone and other potentially hazardous gasses. This is not a problem if the tests are made in chambers vented to the outside. If the tests are not safely vented, it is important to note that:

7.3.1 *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.*[5] *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 appriopriate means, such as exhaust vents, to reduce ozone concentrations to acceptable levels in working areas.*

7.4 **Warning—**Oxides of Nitrogen are also hazardous and are generated by this test.

8. Test Specimens

8.1 *Thick Materials (1.4 mm (0.062 in.) and Over)*—Nine specimens with a thickness of 1.4 ± 0.1 mm (0.06± 0.004 in.) are required for each test voltage. For thicker specimens, reduce the thickness to this value and place the small electrode against the original surface. The size of the specimens shall be sufficient to prevent flashover.

8.2 *Thin Materials (Under 1.4 mm (0.062 in.))*—Use sheets of sufficient size to extend under all nine electrodes with an adequate margin to prevent flashover.

9. Conditioning

9.1 Products of corona, in combination with moisture from the atmosphere, often tend to inhibit the corona discharge so as to influence the time to failure. This makes it necessary to clean and condition the specimens prior to testing and to use conditioned air throughout the life test (see X1.2) with a minimum flow rate of 0.5 L/min per test electrode. Unless otherwise specified, the conditions given in 9.1.1 shall be considered standard for these tests, with designations and standard tolerances in accordance Practice D618, condition 40/23/5: T-23/5 (low humidity), or

9.1.1 Condition 40/23/50: T-23/50 (standard laboratory atmosphere).

10. Procedure

10.1 Apply a voltage to the set of test specimens that is higher than the corona inception voltage (see Test Method D1868), but below the level at which failures will be expected to occur in less than 1 day. Select a voltage high enough that some failures occur in <30 days (at 60 Hz). A good starting point is usually 20 kV/mm (500 V/mil).

10.2 It is convenient to truncate the test at the time of median failure to save testing time. When nine specimens are used and the scatter is such that the median failure time is not more than twice the time to first failure, report the median failure time as the time to failure. If the scatter is greater than

[5] Information may be obtained from American Conference of Governmental Industrial Hygienists, Inc. (ACGIH), 1330 Kemper Meadow Dr., Cincinnati, OH 45240, http://www.acgih.org.

this, draw a straight line through the failure time data plotted on Weibull probability paper. Report the time at 50 % failure as the failure time.

10.3 Using the experience of each test to determine the next lower test voltage, obtain data at three or more voltage levels for a curve of voltage stress versus failure time. Continue the tests until a stress of 4 kV/mm (100 V/mil) or a voltage 40 % above the corona-starting voltage, whichever is higher, is reached. Plot the stress in kV/mm (or V/mil) versus the logarithm of the failure time in hours.

10.4 An optional method for the more corona-resistant materials is to accelerate the test by increasing the frequency. Life for some materials is a function of the total number of cycles and not the frequency that produced those cycles (see Appendix X1). Tests at elevated frequency shall be made to overlap the voltage range of the 60-Hz tests to confirm there is a constancy with the number of cycles to failure. This check is effective because departures from constancy are more likely to occur at high stress than low.

11. Report

11.1 Report the following information:

11.1.1 Material, type designation, conditions of fabrication (if known),

11.1.2 Conditioning prior to test (temperature, humidity, and time),

11.1.3 Test conditions (temperature, humidity, and rate of air flow),

11.1.4 Specimen thickness, maximum, minimum, and average values,

11.1.5 Electrode shape and material,

11.1.6 Frequencies used,

11.1.7 Any corona quantities measured (for example, corona-inception voltage, charge, energy, and so forth),

11.1.8 Curve of stress versus logarithm of failure times, and

11.1.9 All failure times for all tests at all voltages, together with all Weibull plots.

12. Precision and Bias

12.1 This test method is used to rate materials in a comparative way with respect to their resistance to prolonged exposure to partial discharge conditions. A precision and bias statement is nonapplicable to this test method.

13. Keywords

13.1 partial discharge; surface discharge; threshold voltage; voltage indurance; voltage stress-time curve; volt-time curve

APPENDIXES

(Nonmandatory Information)

X1. ACCELERATED TESTING BY INCREASING THE TEST FREQUENCY

X1.1 Voltage endurance of solid electrical insulating materials under corona attack may be determined in a shorter length of time if test frequencies higher than 60 Hz are used. The rate of insulation deterioration per cycle is nearly constant on some materials under certain humidity conditions, providing frequency is not raised excessively to the level where dielectric heating begins to shorten insulation life. Frequencies above 2 or 3 kHz are seldom used if the results are to be correlated with those at power frequency.

X1.2 Life measurements on many hydrocarbon plastics have shown a strong dependence on humidity. A linear relationship between life and reciprocal frequency appears to exist when tests are run in a dry (5 % relative humidity) atmosphere compared to an almost exponential relationship at 50 % relative humidity or higher. Fluorocarbon compounds, on the other hand, show a linear relationship with reciprocal frequency regardless of humidity.

X1.3 Frequency acceleration may be used to advantage when comparing compositions with similar chemical structures. In addition, frequency acceleration may be useful in tests used for quality control.

X1.4 Transformers and other circuit components must be chosen that will provide the same wave form as specified in Test Method D149 for the entire range of frequencies to be used in the test. In case of waveform distortion, lifetimes should be compared at equal peak to peak voltages.

X1.5 The manner in which dry air is introduced into the chamber is important. With localized injection (nozzles), the moisture generated by oxidation of hydrocarbons is driven away from the edge of the electrodes. The localized humidity is driven down to that of the supply air at once, and the voltage may be applied at once. On the other hand, if the same total flow of air is introduced remote from the specimens, a considerable time may elapse before the atmosphere at the specimens approaches the dryness of the supply atmosphere. This time delay is numerically several times the ratio of the chamber size to the flow rate of dry air, and with improper design can be tens to hundreds of hours. The use of open trays of desiccant in the test chamber has been found to be much less effective than using nozzles.

X1.6 *Air Supply Manifold and Nozzles*—A manifold shall be provided to deliver air to separate nozzles for each test station. The required air flow rate is 0.5 L/min/specimen. The nozzle orifice should be approximately 0.5 mm in diameter and should rest about 13 mm (0.5 in.) from the electrode. The nozzle is made of electrical insulating material.

X2. PARTIAL DISCHARGE TESTING IN ENCLOSED SYSTEMS

X2.1 Introduction

X2.1.1 In this test method, the voltage endurance test is specified to be carried out in open air. There is no depletion of oxygen or nitrogen around the specimen; any gaseous by-products are dispersed so no concentration is built up. When testing in a completely enclosed system, all the oxygen may ultimately be combined with the insulation under the influence of the discharges. New gaseous products may be released from the specimen. Hence the ambient test atmosphere may change continuously as the test progresses, with the pressure and density becoming greater or less than initial values. A partially enclosed system allows the slow passage of oxygen in or by-product gases out, causing a different ambient atmosphere from either the completely open or the completely closed system. The effects of part ial discharges on insulations are described for the open system in 5.6. The same effects are present in the closed, or semi-closed, systems, but the possible chemical reactions may have a stronger influence on test results.

X2.2 Materials Available for Interaction

X2.2.1 In any completely closed system where partial discharge testing is being performed, materials are present that may combine chemically into products of a destructive nature, influencing the results of the test. A few of these available materials are:

X2.2.1.1 *Air,* including oxygen, nitrogen, and carbon dioxide,

X2.2.1.2 *Water,* present in the air, in the specimen, and on the surfaces of the container and electrode system.

X2.2.1.3 *Electrode Materials,* commonly metal,

X2.2.1.4 *Specimen*—New products may be generated by chemical reactions after exposure to the discharges, and

X2.2.1.5 *Container*—The type of material used for the container can contribute to the interactions.

X2.2.2 Additional test parameters that may affect the results are the relative size of the container and test specimen, the size and number of test specimens being tested, the electrode material, the ambient temperature, and the moisture content of the specimen.

X2.3 Energy for Reactions

X2.3.1 The energy to carry out chemical reactions is available from the voltage source through the partial discharges. Chemical reactions are promoted by chemically active ionized gases, localized high temperatures, the rise in average temperature, and the ultraviolet light generated by the recombination of the ionized gases. Surfaces of the specimen and electrode are bombarded by ionized gas particles causing chemical and mechanical erosion, the eroded surfaces and the dust particles offering large surface areas conducive to chemical attack.

X2.3.2 The amount of available energy, and the energy density, are strongly affected by the magnitude and frequency of the applied voltage and the geometry of the electrode system. Changes in gas composition and pressure will influence energy level and the form and distribution of that energy.

X2.4 Types of Reactions

X2.4.1 The types of chemical reactions that can occur are numerous and dependent on the materials present. Some of these reactions are as follows:

X2.4.1.1 Under the influence of partial discharges, oxygen in the air can form atomic oxygen (an ion) or ozone (an unstable compound). Both of these are much stronger oxidizing agents than the molecular oxygen normally present.

X2.4.1.2 Nitrogen can combine with oxygen and water to form nitrous or nitric acids. Both of these acids are strong corrosive agents and can react with many electrode materials or with the insulation.

X2.4.1.3 Partial discharges impinging on a polymeric insulating material can degrade it to lower molecular weight units, some as small as the monomer, or some containing a few to a few hundred monomer units.

X2.4.1.4 Polymeric materials can be oxidized due to the presence of ozone or atomic oxygen. This oxidation can break the polymer chain to smaller sections (as above) or attack side groups; it can cause crosslinking. Embrittlement or softening can occur depending on the polymer.

X2.4.1.5 The discharges can generate a medium or high conductivity product which may deposit on the specimen and alter the configuration of the applied electric field. As an example, oxalic acid is formed when polyethylene is subjected to discharges in the presence of air and moisture, causing the discharge to diminish or even disappear except for sporadic discharges.

X2.4.1.6 Ionic bombardment can mechanically erode the surface of the material producing dust particles and reducing the insulation thickness.

X2.5 Pressure Effects

X2.5.1 The gases released by insulating materials subjected to partial discharges can raise the pressure, or more specifically, increase the density and change the nature of the test atmosphere. This includes the types of ions formed and also the energy and energy density in the discharge. The pressure may, or may not, rise to the point where further discharges will not occur unless the voltage is increased.

X2.5.2 In a small, closed system, the initial pressure can drop at the onset of partial discharge due to the depletion of oxygen used in oxidizing the insulation. This can be followed by a pressure rise, as stated in X2.5.1.

X2.5.3 In static air systems that are not completely sealed, that is, where the pressure can equalize with atmospheric pressure, different effects can arise since outside air can be pulled into the system when oxygen is depleted, and pressure or density cannot build up to the point where discharges will be extinguished.

X2.6 Evaluation

X2.6.1 This test should be used as a preliminary evaluation to determine if a material merits further consideration. Because of the wide variation in test conditions, it is not possible to extrapolate from a test to actual service conditions unless the two are very similar in materials, geometry, and environment. Relating behavior of two or more materials generally agrees with relative behavior in practice, but not always, due to differences in test and practical parameters.

X3. CIRCUIT FOR VOLTAGE ENDURANCE TEST

X3.1 A circuit that automatically records the time of specimen failure and removes the failed specimen from voltage is shown in Fig. X3.1.

X3.2 The fusing method shown in Fig. X3.2 is useful when testing below 5000 V. A small piece of paper (approximately 10 by 10 mm (3⁄8 by 3⁄8 in.)) is inserted between the 1⁄4-A fuse wire and the chisel-shaped electrode after these parts have been brought into contact with each other. A suitable paper is silicone-impregnated lens tissue about 0.038 mm (0.0015 in.) thick. The small space between the chisel electrode and the fuse wire will permit testing as low as 1500 applied volts and produce a satisfactory arc gap spark when a specimen fails.

X3.3 When testing above 5 kV, the paper may become punctured before specimen failure occurs if the corona current at the electrodes is sufficiently high. If this happens, use two or more thicknesses of paper, or establish an arc gap of 0.25 mm (0.01 in.) or more between the fuse wire and the chisel-shaped electrode.

X3.4 Additional circuit protection is provided in case the specimen-fusing system does not operate. During failure, the continuing current through relay *B* actuates it and places 110 V on the heater of relay *C*. Relay *C* operates the unlatch coil if the 110 V are maintained for more than 15 s.

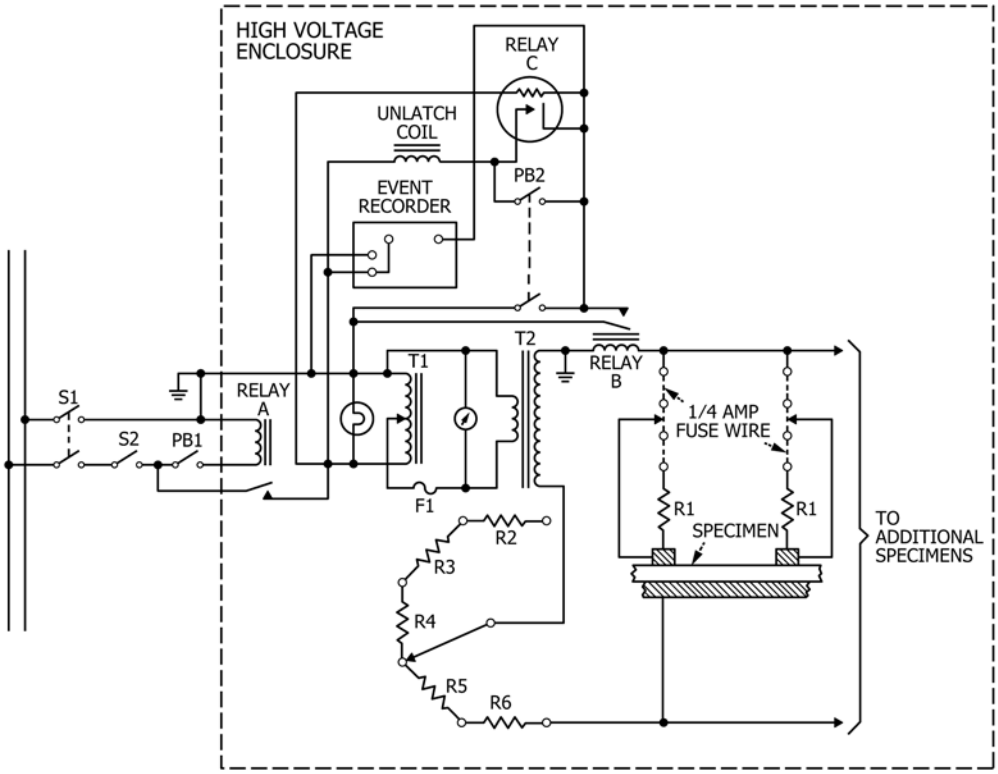
X3.5 A list of components is given with Fig. X3.1. The resistors *R1* through *R6* have been chosen so that operation is possible from 1.5 to 12 kV.

X3.6 A disadvantage of this circuit is that the fuse sometimes does not melt under short-circuit conditions. This can occur when the test is run at lower-than-usual voltages because the specimen is thin or the material has a relatively low breakdown strength.

X3.6.1 An alternative relay-latch-contact-opening mechanism, shown in Fig. X3.3, has been used successfully. Specimen failure current energizes the coil of relay *LM5*, closes the contacts, energizes the coil of the latching relay, and releases the latch, which opens the contacts in the specimen circuit. The latch contacts are designed to open with sufficient clearance to interrupt the high-voltage arc. Auxiliary contacts of relay *LM5* cause the event recorder to indicate the time of failure.

X3.7 All relay coil and magnetic parts must be capable of operating properly and must withstand the power losses associated with whatever frequency is being applied to the relay coil terminals. For example, 60-Hz relays are usually not suitable for 2000-Hz operation. In such cases, where elevated frequencies are being used, d-c relays with the addition of full wave solid-state rectifiers have been used successfully.

X3.8 Coarse and fine adjustments of applied voltage are desirable and can be obtained by adding a second cascade-connected continuously variable autotransformer in the primary circuit. Elevated frequency operation of power transformers requires suitable allowance for frequency and voltage ratings because of increased magnetic-core losses, decreased capacitive reactance of windings, and increased leakage inductive reactance of windings. These may cause excessive current, overload power, overheating, and reduced output, along with poor voltage regulation, resonant effects, and so forth.



Relay *A*—Potter and Brumfield KB 17A, 115-V a-c coil (or equivalent)
Relay *B*—Potter and Brumfield MR 5A, 230-V a-c coil (or equivalent)
Relay *C*—Amperite time delay relay, No. 110N015 (or equivalent)
*PB*1—SPST push button
*PB*2—DPST push button
*S*1—DPST toggle switch
*S*2—Interlocks on all openings to unit
*F*1—5-A Littlefuse
*R*1—50 000-Ω resistor, 50-W wire-wound, or two 25 000-Ω, 25-W resistors in series
*R*2 to *R*6—25 000-Ω resistor, 25-W wire-wound, single-layer
*T*1—5-A continuously variable autotransformer
*T*2—12 to 14.4-kV, 5-kV A distribution line transformer (or equivalent)

FIG. X3.1 Direct-Electrode Voltage Endurance Test Set

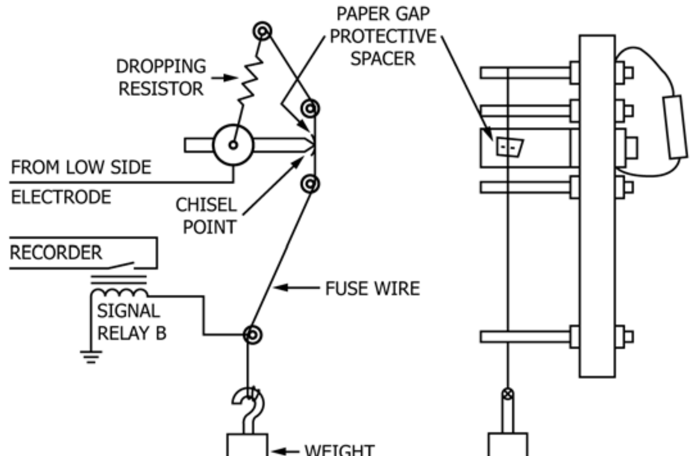


FIG. X3.2 Fusing Method of Circuit Protection

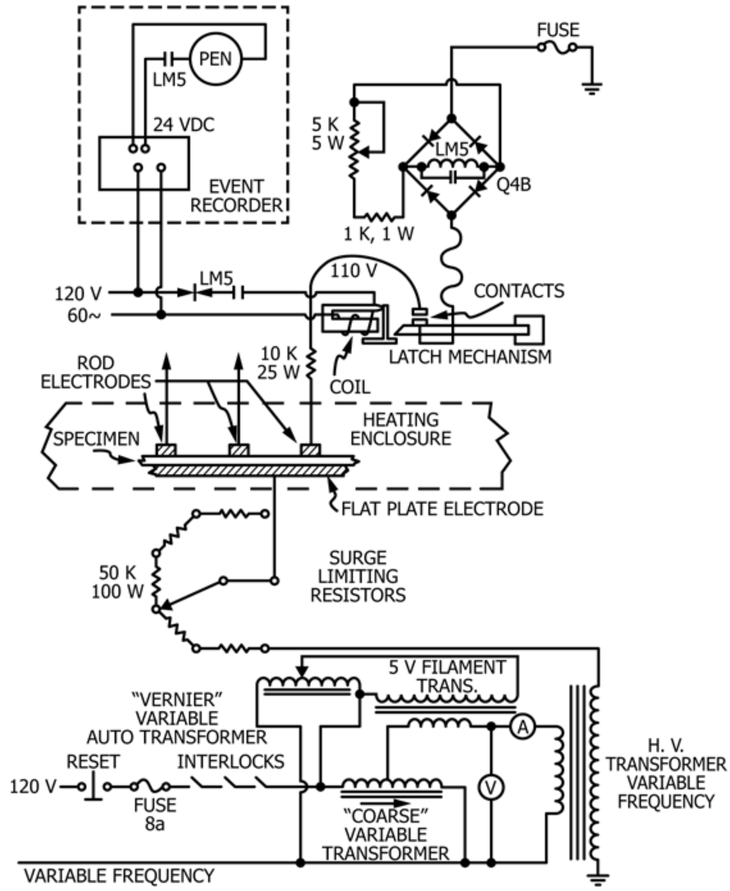


FIG. X3.3 Voltage Endurance Test Circuit