Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates

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Document History:

2024-01-26: Revised by AMPP Standards Committee (SC) 03, Linings and Internal Coatings

2013: Revised by NACE International Task Group (TG) 507, "Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates"

2006: Reaffirmed by NACE Specific Technology Group (STG) 03

1999: Revised by NACE TG T-6A-37

1990: Reaffirmed by NACE TG T-6A-37

1988: Approved by NACE TG T-6A-37

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Foreword

The purpose of this standard is to provide the means of detecting pinholes, flaws, or holidays in a coating system that may result in its premature failure, thereby possibly decreasing the life expectancy of the asset. This standard documents the equipment and the process of using electrical current to identify these holidays in a repeatable and realistic manner for both field and shop coating applications.

Scope

This standard provides procedures for high and low-voltage holiday detection of new, non-conductive coatings or linings applied to conductive (typically metal) substrates.

Rationale

This standard was first issued in 1988. This revision has been prepared as a result of the required periodic review. The 2013 version had not been recently updated due in large part to concerns regarding the inability of the high-voltage spark testing voltage settings to be tied back to any scientific study or mathematical model. The “rule of thumb” of 100 volts per mil of coatings cannot be traced back to any foundational document. Significant shortcomings were seen in the field when this standard was utilized, resulting in many coating systems passing the high-voltage testing standard but failing prematurely in the field. A peer-reviewed paper was presented at the AMPP Annual Conference + Expo 2022 that provided test data and utilized Paschen’s Law and the breakthrough voltage of air to provide additional data for this.

Referenced Standards and Other Consensus Documents

Unless specifically dated, the latest edition, revision, or amendment of the documents listed in the table below shall apply.

AMPP/NACE/SSPC, www.ampp.org:	
NACE/ASTM G193	Standard Terminology and Acronyms Relating to Corrosion
SSPC-PA 2	Procedure for Determining Conformance to Dry Coating Thickness Requirements
SSPC-PA 9	Measurement of Dry Coating Thickness Using Ultrasonic Gages

ASTM International, www.astm.org:	
ASTM D149	Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
ASTM D7091	Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals
ASTM D6132	Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Coating Thickness Gage

In AMPP standards, the terms *shall* and *must* are used to state requirements and are considered mandatory. The term *should* is used to state something that is recommended but is not considered mandatory. The term *may* is used to state something considered optional.

Section 1: General

1.1 This standard provides procedures for high-voltage spark testing and low-voltage spark testing of new non-conductive coatings and/or linings on conductive substrates and is broken up into two sections: High-Voltage Testing and Low-Voltage Testing.

1.2 Electrical testing to determine the presence and number of discontinuities in a coating is performed on a nonconductive coating applied to a conductive substrate. The allowable number of discontinuities should be determined before conducting this test.

1.3 This standard is not intended to provide data on service life, adhesion, or film thickness of an applied coating system.

1.4 This standard is intended for use only with newly applied coatings applied to conductive substrates. Inspecting a coating previously exposed to an immersion condition could result in damage to the coating or could produce an erroneous detection of discontinuities due to permeation or moisture absorption of the coating. Deposits may also be present on the surface, causing telegraphing.

The use of a high-voltage spark tester on previously exposed coatings can result in a spark that damages an otherwise sound coating. A low-voltage wet sponge tester may be used without damaging the coating but can produce erroneous readings.

1.5 To prevent damage to a coating if a high-voltage spark tester is being used, the total film thickness of the coating system above the peaks of the surface profile shall be considered in selecting the appropriate voltage for the detection of discontinuities. Substrates with 'rogue peaks' or highly variable surface conditions (such as ductile iron) are subject to damage in areas where the DFT is significantly lower than the DFT used to calculate the test voltage.

1.6 The coating manufacturer shall be consulted to obtain the following information, which can affect the accuracy of the tests described in this standard to determine discontinuities:

a) The length of time required to adequately dry or cure the applied coating before testing. Solvents retained in an uncured coating may form an electrically conductive path through the film to the substrate.

b) Whether the coating contains electrically conductive fillers, pigments, or additives that may affect the normal dielectric properties.

c) Any unique dielectric strength properties specific to a coating manufacturer's coating that would preclude holiday detection.

d) Recommended test voltage based on specific coating or lining, coating /lining thickness, environment, and specific type of substrate being coated (i.e., steel, ductile iron, stainless, etc.).

Section 2: Definitions

For the purpose of this standard, the definitions from NACE/ASTM G193 shall apply. The following additional terms and definitions also apply:

Coating: (1) a liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film. (2) (in a more general sense) a thin layer of solid material on a surface that provides improved protective, decorative, or functional properties.

Dielectric Strength: The maximum voltage an insulating material can withstand without undergoing electrical breakdown. It is tested in accordance with ASTM D149.

Discontinuity: (1) An interruption in the normal physical structure of conformation of a coating such as cracks, laps, seams, inclusions, porosity, or holidays. (A discontinuity does not necessarily affect the usefulness of the coating.) (2) A condition in which the electrical path through a structure is interrupted by a device that acts as a dielectric or insulating fitting.

Electrical Breakdown: A process that occurs when an insulating material, subjected to high enough voltage, suddenly becomes an electrical conductor, and electrical current flows through it.

Electrical Resistance: A fundamental property of a material that measures how strongly it resists electric current.

Electrode: A conductive surface that is charged by the holiday detector to a desired test voltage and placed against the coating to be tested. Common electrode configurations include brushes and springs (primarily used for detection on the exterior of pipes or other cylindrical surfaces).

High-voltage Voltmeter: A device capable of measuring the voltage between the electrode and the ground connection of a high-voltage holiday detector. When used with a Pulse DC high-voltage holiday detector, the high-voltage voltmeter shall be a peak reading voltmeter.

Holiday: A discontinuity in a protective coating that exposes unprotected surfaces to the environment.

Holiday detection: Testing of a coating system for holidays using an instrument that applies a voltage between the external surface of the coating and a conductive substrate.

Pinhole: A minute hole through a coating or coats that exposes an underlying coat or the substrate.

Pulse-type detector: A type of holiday detector that supplies a high-voltage pulse of very short duration (e.g., a pulse duration of 0.0002 seconds at a rate of 30 pulses per second).

Telegraphing: Current that travels through a conductive path to a discontinuity, causing an erroneous discontinuity test result.

Section 3: High-Voltage Testing

3.1 Significance and Use

High-voltage holiday detectors use the principle of electrical breakdown to locate holidays. Typically, a charged electrode is placed in contact with the coating, and the detector is grounded to the coated substrate. When an electrical breakdown occurs, electric current flows between the high-voltage holiday detector's electrode and the conductive substrate. A high-voltage holiday detector detects this flow of current and emits an audible and/or visible alarm.

The generally accepted dielectric strength of air in laboratory conditions is 3,000 V/mm (75 V/mil).[1] However, in practice the dielectric strength varies based on factors such as the electrode shape, distance, ambient temperature, and the presence of airborne contaminants. Paschen's law can be used to calculate the dielectric strength of air for various atmospheric conditions and distances, and yields values for dielectric strength of air up to 6,900 V/mm (175 V/mil) for a 10 mil (254 micron) coating.

The dielectric strength of coatings varies based on the coating properties and coating dry film thickness (DFT). As a general rule of thumb, the dielectric strength of many epoxies is roughly 20,000 V/mm (500 V/mil).[2] However, other coatings such as fusion-bonded epoxies have dielectric strengths of up to 46,000 V/mm (1,180 V/mil).[3] Some coatings, particularly coatings that have been subjected to immersion service, have significantly lower dielectric strengths.

High-voltage holiday detectors operate at an electrode voltage that is higher than the dielectric strength of air at the measured coating thickness, but lower than the dielectric strength of the coating. In this manner, electrical breakdown (and an alarm on the high-voltage holiday detector) will not occur when the electrode is in contact with the coating but will occur if there are any areas where the coating is missing and only air is present.

Factors such as debris on the surface of the electrode or coating, local variations in coating thickness, and imperfections in the electrode (such as the gaps between strands in a brush or coils in a spring) can increase the voltage required to facilitate electrical breakdown (and an alarm on the high-voltage holiday detector). It is therefore advisable to use a test voltage above the breakdown strength of air at the measured coating thickness.

Electrical breakdown through a coating typically damages it. It is therefore advisable to use a test voltage significantly below the breakdown strength of the coating, to prevent undesired damage in areas of lower coating thickness.

3.2 Apparatus

A high-voltage holiday detector consists of an electrical energy source, a means of displaying the set voltage, an electrode, a ground wire/connection, and a visible and/or audible alarm.

Energy Source: This can be identified as either a pulse or direct current type. A pulse-type high-voltage holiday detector generates a cycling, high-voltage pulse with a typical voltage repetition rate of between 20 and 60 Hz, while a direct current type generates continuous voltage.

Electrode: The electrode shall be of the type capable of maintaining continuous contact with the surface being inspected, including fasteners, raised areas, etc. It shall be kept clean and free of foreign material.

Alarm: An audible and or visual signal that a holiday has been detected. Activation of the alarm shall be readily obvious to the operator under test conditions.

High-voltage Voltmeter: An instrument capable of measuring the voltage difference between the electrode (or part of the high-voltage holiday detector electrically continuous with, and at the same voltage as, the electrode), and the ground connection. The high-voltage voltmeter can be integral to the high-voltage holiday detector, or a separate external device.

3.3 Calibration

The high-voltage voltmeter shall be calibrated by the manufacturer, its authorized agent, or an accredited calibration laboratory in a controlled environment using a documented process. It should be calibrated at the range of voltages to be used during testing.

A certificate of calibration showing traceability to a national reference measurement standard is issued after calibration, and it (or a copy) should be retained with the instrument.

There is no standard time interval for re-calibration, nor is one absolutely required, but a calibration interval can be established based on experience and the work environment. A one-year calibration interval is a typical frequency suggested by many instrument manufacturers.

3.4 Equipment Setup and Verification

3.4.1 Grounding Requirements

The holiday detector shall be properly grounded throughout the test. If the instrument is not properly grounded, it will fail to detect holidays.

The ideal grounding method is a direct electrical connection to the conductive substrate of the material being tested. Typically, an alligator clip, magnet, or other means of attachment is connected to the ground wire and secured to a bare area of the substrate. Care should be taken to ensure the grounding location is electrically connected to the area being tested and that there is no coating or debris between the alligator clip and the substrate.

If no area of bare substrate is available, high voltage holiday detectors equipped with Pulse DC technology can use alternative methods of grounding such as a ‘grounding mat’ or ‘trailing lead.’ These methods rely on the capacitive coupling of the ground lead with the substrate or an area electrically coupled to the substrate. Capacitive coupling can be affected by factors such as environmental conditions, soil/coating composition, and soil/coating moisture content, and therefore should be regularly verified to ensure the high voltage holiday detector remains grounded.

3.4.2 Electrode Selection

The electrode used to test an area of a coating shall be of sufficient geometry to contact the entire measurement area. It shall not distort or damage the coating. The electrode shall be free of any dirt or contaminants. If the electrode is not capable of contacting the entire measurement area in a single pass, such as the area where the spring electrode connects to the high-voltage holiday detector, multiple passes shall be made such that the electrode is in contact with all areas of the coating during at least one pass.

3.4.3 Voltage Setting

The voltage setting shall be based on the average DFT in a given area as measured in accordance with ASTM D7091 or ASTM D6132.

If agreed to by the owner, the voltage setting may be based on the average DFT in a given area as measured in accordance with SSPC-PA 2 or SSPC-PA 9. The procedures for high voltage holiday detection can be used for coating thicknesses as low as 250 µm (10 mils) if the dielectric strength of the coating exceeds the values in Table A1, or if permitted by the specifier or coating manufacturer. Historically high voltage holiday detection has been utilized for coating thicknesses greater than 500 µm (20 mils) and it is the only approved method of holiday detection above 500 µm (20 mils).

The test voltage shall not exceed the dielectric strength of the coating or electrical breakdown may occur through the coating, damaging it. For most common coatings, this is not a concern.

The coating manufacturer should be consulted for proper test equipment and inspection voltage based on the specific coating/lining being applied and the specific type of substrate. For substrates such as ductile iron, where the surface roughness is exceptionally variable, it is advisable to defer to the coating manufacturer’s written recommended test voltages

NOTE: Using voltages lower than those recommended in this section may increase the likelihood of failing to detect all holidays.

The test voltage shall be 1.5 times the dielectric strength of air at the measured DFT as calculated using Paschen’s law, plus 1,500 volts. The voltage can be calculated as shown in Equations (1) and (2) below: [4]

$$V=1500+1.5*[170+2.48d+58\sqrt{d}\,] \quad \text{(microns)} \tag{1}$$

$$V=1500+1.5*[170+63d+293\sqrt{d}\,] \quad \text{(mils)} \tag{2}$$

where:
V = the test voltage (volts)
d = the coating thickness.

A lookup table for common coating thickness ranges is tabulated in Appendix A (nonmandatory).

A voltage setting that is greater than the theoretical dielectric strength of air ensures that factors such as those listed in Paragraph 3.1 are less likely to fail to detect a holiday. If efforts are taken to account for those factors, and there is agreement among all interested parties, a lower test voltage can be acceptable. For example, a lower voltage setting may be necessary when the calculated voltage is near the dielectric strength of the coating, or the calculated voltage at the average measured DFT exceeds the capabilities of available holiday detection equipment. If voltages are decreased, a mockup test of a known holiday/discontinuity shall be conducted to ensure consistent detection is still achieved.

The basis of the testing voltage setting is described in Appendix B (nonmandatory).

3.4.4 Verification Frequency

Verification of the Test Voltage and Verification of Operation shall be performed:

- Before and after each period of use
- If the high-voltage holiday detector has been dropped
- If the electrode has changed
- If the coating or coating thickness changes

3.4.5 Verification of Test Voltage

NOTE: Some high-voltage holiday detectors include an integral high-voltage voltmeter and a means of adjusting the electrode voltage based on the output of the high-voltage voltmeter, thereby performing the following steps automatically.

3.4.5.1 Ensure the detector is grounded in accordance with Paragraph 3.4.1.

3.4.5.2 The test voltage shall be verified while connected to the electrode being used for testing, while the electrode is in contact with the coating to be tested in an area free of holidays.

3.4.5.3 Connect the ground connector from the high-voltage voltmeter to the ground connector of the high-voltage holiday detector.

3.4.5.4 Turn the high-voltage holiday detector on and adjust the voltage setting to the desired test voltage. Activate the voltage output to charge the electrode.

3.4.5.5 Place the high-voltage voltmeter against the electrode of the high-voltage holiday detector.

3.4.5.6 Ensure the measured voltage on the high voltage voltmeter is within tolerance of the desired test voltage. If required, adjust the voltage output of the high-voltage holiday detector.

3.4.6 Verification of Operation

3.4.6.1 Ensure the detector is grounded in accordance with Paragraph 3.4.1.

3.4.6.2 The test surface shall be clean, dry, and free of oil, dirt, and other contaminants. Sufficient drying or curing of the coating shall be allowed before conducting a test. The length of time required for drying or curing shall be obtained from the coating manufacturer. Solvents retained in the coating before curing could produce erroneous indications.

3.4.6.3 Locate a known holiday in the coating where a small area (less than 1 mm [0.040 inch] diameter) of the substrate is exposed. If a known defect is not available, create a small defect using a punch or small drill bit.

NOTE: For some applications, it may not be feasible or desirable to create a known holiday in the coating. in such a situation, interested parties should agree on how the operation of the high-voltage holiday detector can be verified. One option is to verify on a companion panel with similar properties to the application being tested.

3.4.6.4 Place the electrode on the coating to be tested at least 25 mm (1 in) away from the known holiday.

3.4.6.5 Turn the high-voltage holiday detector on and activate the voltage output to charge the electrode.

3.4.6.6 Sweep the electrode across the known defect, and ensure that the alarm activates when, and only when, the electrode is near the known holiday.

3.4.6.7 Some holiday detectors include an alarm sensitivity adjustment option. If the detector does not alarm as expected while performing Paragraph 3.4.6.6, the alarm sensitivity may be adjusted so that the alarm sounds when, and only when, the electrode is near the known holiday.

3.5 Inspection Process

3.5.1 Ensure the high-voltage holiday detector is properly grounded in accordance with Paragraph 3.4.1.

3.5.2 The electrode shall be physically traversed across 100% of the area to be inspected.

3.5.3 The electrode shall be traversed over the coating at a rate not to exceed 0.3 m/s (1 ft/s) ensuring the electrode reaches all coated areas. Overlapping passes are permitted if necessary to ensure 100% coverage.

3.5.4 An alarm may indicate one or more holidays across the length of the electrode. If using a brush electrode, move the electrode perpendicular to the original test direction to identify the location and number of holidays. If using a spring electrode, back the electrode a small distance away from the location where the alarm sounded, activate the voltage output, and move a conductive rubber paddle around the circumference of the pipe while in contact with the electrode to precisely locate the holiday(s).

3.5.5 Discontinuities that require repair shall be identified with a coating-safe marker that is compatible with the repair coating or one that is easily removed. Marking the defects with masking tape or painter’s tape is acceptable, provided the tape adhesive does not affect the subsequent repair.

3.5.6 Once holidays are detected and repaired, they shall be reinspected until the area is determined to be holiday-free.

Section 4: Low-Voltage Holiday Detectors

4.1 Significance and Use

Low-voltage holiday detectors use the principle of electrical resistance to locate holidays. Typically, a wet sponge, charged to a specified electrical voltage, is placed in contact with the coating, and the detector is grounded to the conductive substrate. A low-voltage holiday detector measures the resistance between the wet sponge and the ground connector.

Most coatings are insulators, meaning they have relatively high electrical resistance. Tap water is a conductor, meaning it has relatively low electrical resistance. When the wet sponge is placed on a continuous, defect-free coating, the resistance between the sponge and the substrate is high. If the wet sponge encounters a defect in the coating and the water is therefore able to find a path directly between the wet sponge and the substrate, the resistance between the sponge and the substrate is low.

A low-voltage holiday detector emits an alarm when the resistance between the sponge and the ground connector (and therefore the substrate) drops below a pre-determined threshold, indicating the presence of a defect that has allowed water to make contact with the substrate.

4.2 Apparatus

A low-voltage holiday detector consists of an electrical energy source, a wet sponge, a ground wire/connection, and a visible and/or audible alarm. These components are described below:

Electrical energy source: An electronic device powered by a self-contained battery with voltages ranging from 9 to 90V DC.

Sponge: An open-cell cellulose sponge mounted in a configuration suitable to contact the coating in the desired application.

Water: Clean tap water. Saltwater or deionized water shall not be used, as they can negatively affect the operation of the low-voltage holiday detector.

Wetting Agent (Optional): A low-sudsing wetting agent, (such as that used in photographic film development) diluted to the specified concentration can be used in accordance with Paragraph 4.4.3 to reduce the surface tension of the water, allowing it to penetrate deeper, smaller defects.

Alarm: An audible and or visual signal that a holiday has been detected. Activation of the alarm shall be readily obvious to the operator under test conditions.

Voltmeter: An instrument capable of measuring the voltage difference between the sponge and the ground connection. The voltmeter can be integral to the low-voltage holiday detector, or a separate external device.

Resistors: Resistors may consist of a variable resistance “decade box” device, or individual resistors as required in Paragraph 4.4.5.

4.3 Calibration

The low-voltage voltmeter shall be calibrated by the manufacturer, its authorized agent, or an accredited calibration laboratory in a controlled environment using a documented process. It should be calibrated at the voltages and resistances to be used during testing.

A certificate of calibration showing traceability to a national reference measurement standard is issued after calibration, and it (or a copy) should be retained with the instrument.

There is no standard time interval for re-calibration, nor is one absolutely required, but a calibration interval can be established based on experience and the work environment. A one-year calibration interval is a typical frequency suggested by many instrument manufacturers.

4.4 Equipment Setup and Verification

4.4.1 Grounding Requirements

The low-voltage holiday detector shall be properly grounded throughout the test. If the instrument is not properly grounded, it will fail to detect holidays.

The ideal grounding method is a direct electrical connection to the conductive substrate of the material being tested. Typically, an alligator clip, magnet, or other means of attachment is connected to the ground wire and secured to a bare area of the substrate. Care should be taken to ensure the grounding location is electrically connected to the area being tested and that there is no coating or debris between the alligator clip and the substrate.

4.4.2 Dry Film Thickness

The surface shall be clean, dry, and free of oil, dirt, and other contaminants. Sufficient drying or curing of the coating shall be allowed before conducting a test. The length of time required for drying or curing shall be obtained from the coating manufacturer. Solvents retained in the coating before curing could produce erroneous indications.

The dry film thickness of the test area shall be measured in accordance with ASTM D7091.

The procedures for Low Voltage Holiday Detection can be used for coating thicknesses up to 500 µm (20 mils). If the coating exceeds 500 µm (20 mils), the procedures for high-voltage holiday detection shall be used.

4.4.3 Sponge Selection

The sponge used to test an area of a coating shall be of sufficient geometry to contact the entire measurement area. The sponge shall be free of any dirt or contaminants. Sponges configured in a roller configuration can be used to reduce sponge wear and operator fatigue when measuring large areas.

The sponge shall be saturated with tap water. The sensitivity of the test shall be increased for coating thicknesses exceeding 250 µm (10 mils) by adding a wetting agent to the water, at the concentration recommended by the manufacturer. If the wetting agent is used, it shall be washed from any areas that require repair or top coating to prevent interference with adhesion.

4.4.4 Verification Frequency

Verification of the voltage output, sensitivity, and operation shall be performed:

- Before and after each period of use
- If the low-voltage holiday detector has been dropped
- If the sponge has been changed

4.4.5 Verification of Voltage Output

Set the test voltage and sensitivity as required by contract specifications or the coating manufacturer's datasheet. If no voltage is specified, a test voltage of 67.5V and sensitivity of 90 kiloohms are typical settings.

NOTE: Unlike high-voltage holiday detectors, the voltage setting does not require adjustment based on coating thickness.

Turn on the low-voltage holiday detector. Connect the positive/red lead of the voltmeter to the sponge and connect the negative/black lead of the voltmeter to the ground connector.

Ensure that the reading on the voltmeter matches the setting on the low-voltage holiday detector, within the combined tolerance of the voltmeter and low-voltage holiday detector.

4.4.6 Verification of Sensitivity

Connect a resistor (or variable resistance device) that is 10 kiloohms below the specified sensitivity setting between the sponge and ground connector. The alarm should activate.

Connect a resistor (or variable resistance device) that is 10 kiloohms above the specified sensitivity setting between the sponge and ground connector. The alarm should not activate.

Ensure the low-voltage holiday detector is properly grounded.

Turn the low-voltage holiday detector on and activate the voltage output to charge the sponge.

Place the sponge against the low-voltage holiday detector's ground connector. The alarm should activate. If the alarm fails to activate, the equipment should be considered inoperative.

4.4.7 Verification of Operation

4.4.7.1 Attach the detector's ground clamp to a nearby ground plate/rod.

4.4.7.2 The test surface shall be clean, dry, and free of oil, dirt, and other contaminants. Sufficient drying or curing of the coating shall be allowed before conducting a test. The length of time required for drying or curing shall be obtained from the coating manufacturer. Solvents retained in the coating before curing could produce erroneous indications. Place the electrode against the low-voltage holiday detector's ground connector. The alarm should activate.

4.4.7.3 Locate a known holiday in the coating, where a small area (less than 1 mm [0.40 inch] diameter) of the substrate is exposed. If a known defect is not available, create a small defect using a punch or small drill bit.

NOTE: For some applications, it may not be feasible or desirable to create a known holiday in the coating. In such a situation, interested parties should agree on how the operation of the low-voltage holiday detector can be verified. One option is to verify on a companion panel with similar properties to the application being tested.

4.4.7.4 Place the electrode on the coating to be tested at least 25 mm (1 in) away from the known holiday.

4.4.7.5 Turn the low-voltage holiday detector on.

4.4.7.6 Sweep the electrode across the known defect, using the procedure outlined in Paragraph 4.5.3. Ensure that the alarm activates when, and only when, the electrode is near the known holiday.

4.5 Inspection Process

4.5.1 Ensure the low-voltage holiday detector is properly grounded.

4.5.2 The electrode shall be physically traversed across 100% of the area to be inspected.

4.5.3 The sponge shall be traversed over the coating at a rate not to exceed 0.3 m/s (1 ft/s) ensuring the electrode reaches all coated areas. Overlapping passes are permitted if necessary to ensure 100% coverage. Once a holiday is detected, the electrode may be passed over the area slowly in different orientations to localize the holiday for repair.

4.5.4 Discontinuities that require repair shall be identified with a coating-safe marker that is compatible with the repair coating or one that is easily removed. Marking the defects with masking tape or painter's tape is acceptable, provided the tape adhesive does not affect the subsequent repair.

4.5.5 Once holidays are detected and repaired, they shall be reinspected until the area is determined to be holiday-free.

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3. Data Sheet, 3M Scotchkote Fusion-Bonded Epoxy Coating 6233, https://multimedia.3m.com/mws/media/38362O/3mtm-scotchkotetm-fusion-bonded-epoxy-coating-6233.pdf (February 3, 2023).

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Appendix A
Recommended Voltage Settings for High-Voltage Holiday Testing for Various Coating Thicknesses (Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein

Table A1 outlines the recommended testing voltages per the equations in Paragraph 3.4.3. Voltage (V) values are rounded to the nearest 100V.

Table A1
Recommended Voltage Settings for High-Voltage Holiday Testing

Mils	Microns	Voltage (kV)	V/mil
10	254	**4.1**	410
12	305	**4.4**	367
14	356	**4.7**	336
16	406	**5.0**	313
18	457	**5.3**	294
20	508	**5.6**	280
22	559	**5.9**	268
24	610	**6.2**	258
26	660	**6.4**	246
28	711	**6.7**	239
30	762	**7.0**	233
32	813	**7.3**	228
34	864	**7.5**	221
36	914	**7.8**	217
38	965	**8.0**	211
40	1016	**8.3**	208
42	1067	**8.6**	205
44	1118	**8.8**	200
46	1168	**9.1**	198
48	1219	**9.3**	194
50	1270	**9.6**	192
52	1321	**9.8**	188
54	1372	**10.1**	187
56	1422	**10.3**	184
58	1473	**10.6**	183
60	1524	**10.8**	180
62	1575	**11.1**	179
64	1626	**11.3**	177
66	1676	**11.6**	176
68	1727	**11.8**	174
70	1778	**12.0**	171
72	1829	**12.3**	171
74	1880	**12.5**	169

Mils	Microns	Voltage (kV)	V/mil
76	1930	**12.8**	168
78	1981	**13.0**	167
80	2032	**13.2**	165
82	2083	**13.5**	165
84	2134	**13.7**	163
86	2184	**13.9**	162
88	2235	**14.2**	161
90	2286	**14.4**	160
92	2337	**14.7**	160
94	2388	**14.9**	159
96	2438	**15.1**	157
98	2489	**15.4**	157
100	2540	**15.6**	156
102	2591	**15.8**	155
104	2642	**16.1**	155
106	2692	**16.3**	154
108	2743	**16.5**	153
110	2794	**16.7**	152
112	2845	**17.0**	152
114	2896	**17.2**	151
116	2946	**17.4**	150
118	2997	**17.7**	150
120	3048	**17.9**	149
122	3099	**18.1**	148
124	3150	**18.4**	148
126	3200	**18.6**	148
128	3251	**18.8**	147
130	3302	**19.0**	146
132	3353	**19.3**	146
134	3404	**19.5**	146
136	3454	**19.7**	145
138	3505	**19.9**	144
140	3556	**20.2**	144

Table A1
Recommended Voltage Settings for High-Voltage Holiday Testing

Mils	Microns	Voltage (kV)	V/mil
142	3607	**20.4**	144
144	3658	**20.6**	143
146	3708	**20.8**	142
148	3759	**21.1**	143
150	3810	**21.3**	142
152	3861	**21.5**	141
154	3912	**21.7**	141
156	3962	**22.0**	141
158	4013	**22.2**	141
160	4064	**22.4**	140
162	4115	**22.6**	140
164	4166	**22.9**	140
166	4216	**23.1**	139
168	4267	**23.3**	139
170	4318	**23.5**	138
172	4369	**23.8**	138
174	4420	**24.0**	138
176	4470	**24.2**	138
178	4521	**24.4**	137
180	4572	**24.6**	137
182	4623	**24.9**	137
184	4674	**25.1**	136
186	4724	**25.3**	136
188	4775	**25.5**	136
190	4826	**25.8**	136
192	4877	**26.0**	135
194	4928	**26.2**	135
196	4978	**26.4**	135
198	5029	**26.6**	134
200	5080	**26.9**	135
202	5131	**27.1**	134
204	5182	**27.3**	134
206	5232	**27.5**	133
208	5283	**27.7**	133
210	5334	**28.0**	133
212	5385	**28.2**	133
214	5436	**28.4**	133
216	5486	**28.6**	132
218	5537	**28.8**	132
220	5588	**29.0**	132
222	5639	**29.3**	132
224	5690	**29.5**	132
226	5740	**29.7**	131
228	5791	**29.9**	131
230	5842	**30.1**	131
232	5893	**30.4**	131
234	5944	**30.6**	131
236	5994	**30.8**	131
238	6045	**31.0**	130
240	6096	**31.2**	130
242	6147	**31.4**	130
244	6198	**31.7**	130
246	6248	**31.9**	130
248	6299	**32.1**	129
250	6350	**32.3**	129
252	6401	**32.5**	129
254	6452	**32.7**	129
256	6502	**33.0**	129
258	6553	**33.2**	129
260	6604	**33.4**	128
262	6655	**33.6**	128
264	6706	**33.8**	128
266	6756	**34.0**	128
268	6807	**34.3**	128
270	6858	**34.5**	128
272	6909	**34.7**	128
274	6960	**34.9**	127

Appendix B
Basis for Testing Voltages
(Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein

This appendix outlines the reasoning for the testing voltages outlined in Paragraph 3.4.3. The basis of the testing voltages is "Why Voltage Matters for High Voltage Holiday Testing on Steel" by Walker, O'Dea et al.[5] The paper completed a thorough review studying the implications of voltage selection when high-voltage holiday testing over a range of coating thicknesses. Based on over 100,000 holiday tests, the paper concluded that much higher voltages are required to accurately and consistently detect holidays when high-voltage holiday testing. Figure B1 displays the data points from the study with the equations in Paragraph 3.4.3.

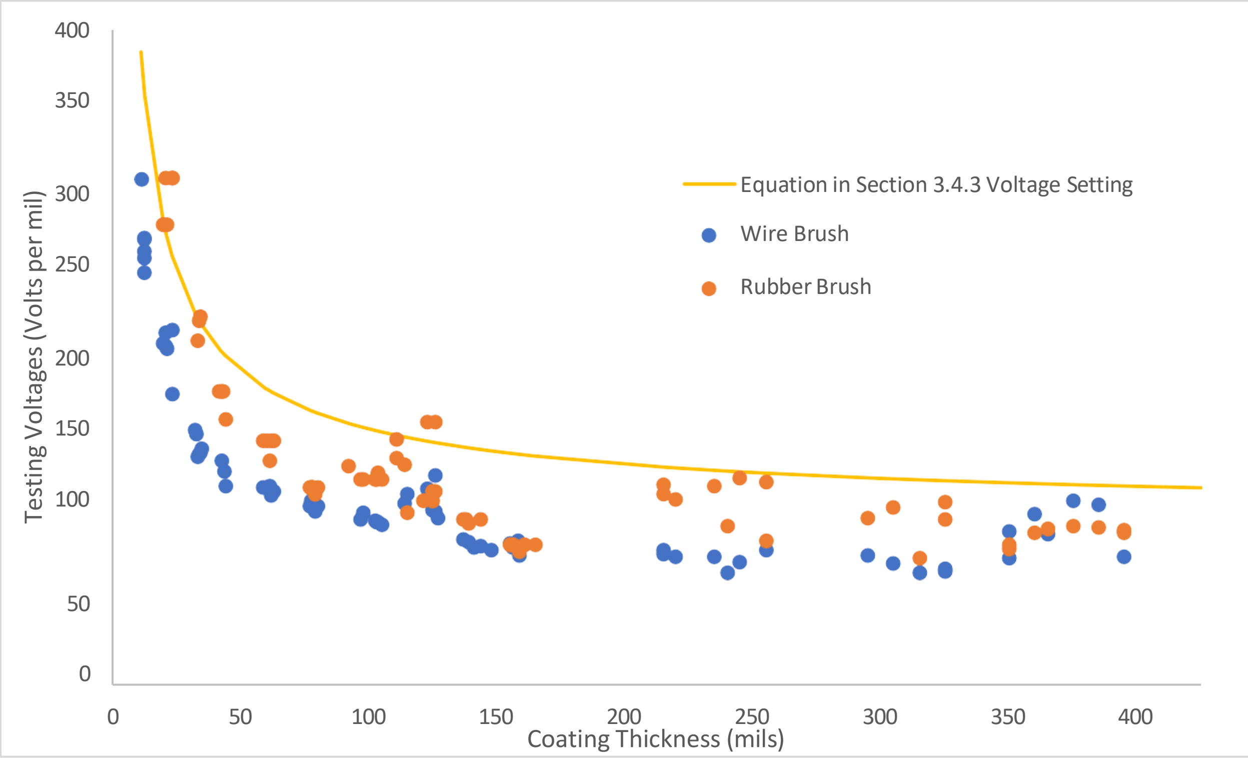

Figure B1: Data Points from AMPP Paper No. 17662 Compared to Testing Voltages

As seen in Figure B1, the provided testing voltages allow for consistent holiday detection across all thicknesses and types of electrodes (brushes). While there was a difference noted between the different brush materials, the prescribed testing voltage setting in this standard provides the user confidence during testing, independent of the brush type. This study/data provided the committee with the basis for the recommended testing voltages and prescribed equation.