

Why Voltage Matters for High Voltage Holiday Testing on Steel

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ABSTRACT

In corrosive environments it is considered essential to produce a continuous protective coating for long term performance. Non continuous films provide opportunities for premature failure of the coating through isolated corrosion and undercutting. To reduce the risk of premature failure for thick film systems, high voltage holiday testing is completed using specialized equipment. High voltage holiday testing is the practice of using high voltage equipment to detect discontinuities in a coating system.

The rule of thumb throughout the US industry has typically been a minimum of 100 volts per mil of coating (1/1000 inch) as the basis of voltage settings. It is believed 100 volts/mil allows for the detection of holidays while not posing a risk of damaging the coating system. Consequences of incorrect voltage settings can range from undetected holidays to damaged coatings. The purpose of this paper will be to discuss the concept behind high voltage holiday testing, the theoretical required voltage to bridge the air gap and experimental findings of the required voltages for holiday detection on a range of thick film coatings.

Key words: high voltage holiday testing, pinholes, holidays, protective coatings, voltage, methods, experiment

INTRODUCTION

A holiday is defined as a pinhole or discontinuity in a coating lining. These discontinuities are frequently very small and not readily visible and create a pathway for oxygen and an electrolyte to cause deterioration of the underlying substrate. These defects will tend to reduce the life expectancy of a coating in service, particularly if the service is to include immersion, such as the lining of a tank or a pipe.

Due to the small size of most holidays, visual inspection can be an inadequate method on its own for locating all holidays. The use of holiday equipment paired with a visual inspection can help reduce the risk of missed or unfound holidays. Holiday detection can be used on metallic substrates, such as carbon steel, ductile iron, stainless, or concrete substrates with sufficient moisture content.

There are two types of holiday detection; low voltage and high voltage holiday testing. Low voltage holiday testing employs a wet sponge to bridge the space between the equipment and conductive surface. High voltage testing is typically only used for coatings thicker than 20 mils as the higher voltage allows for bridging of the greater thickness. High voltage testing on thickness less than 20 mils is possible, but care should be taken to not exceed the dielectric strength of the coating.

For the purpose of this paper, the only application of high voltage holiday testing will be considered on carbon steel substrates. Concrete substrates can vary significantly in terms of conductivity based on its moisture content, rebar cover, and the position/distance to the grounding element.

There are several industry consensus standards that outline recommended voltages based on a coating thickness and substrate. Values between the standards can vary significantly, thus experimental testing to assess the required voltages was completed for a range of coating thickness. Comparison and discussion of the results are detailed in the paper.

VOLTAGE SETTINGS

Proper voltage selection based on coating thickness helps ensure accurate testing and detection of discontinuities without adversely affecting the dielectric insulative properties of the coating. However, testing voltages have long been a matter of great discussion among coating manufacturers, applicators, and inspectors. In brief, it is the consensus of the industry that the high voltage spark needs to bridge the air gap between the exploring electrode and the underlying substrate. Beyond that exercising this concept may not be well understood.

Independent laboratory investigations by Dr. Whitehead and J. Peak, and their respective works published in 1911, determined the dielectric strength of air is approximately 76 volts per mil [1]. It is believed that the coatings industry adapted these findings to establish the 100 volts per mil “rule of thumb” for voltage selection when high voltage holiday testing protective coatings and linings. In fact, the 100 volts per mil “rule of thumb” is promulgated in the NACE Coating Inspector Program (CIP) – Level 1 training course without discussion on coating thickness [2]. But is the 100 volts per mil “rule of thumb” sufficient to detect discontinuities with any degree of certainty? And what about the various industry standards that prescribe much higher voltage settings than the 100 volts per mil “rule of thumb”?

Is there merit with the higher than the “100 volts per mil” voltage settings contained within these industry standards to sufficiently locate discontinuities within a coating film or are they potentially damaging the protective coating by exceeding the material’s dielectric strength?

Let’s begin by discussing the definition of the dielectric strength of air and the dielectric strength of a protective coatings and the air that surrounds them.

Dielectric Strength of Air

There are two defined critical points: the disruptive critical voltage (dielectric strength) and the visual critical voltage. The visual critical voltage, known as the corona, will not be discussed further as it does not pertain to the discussion of holiday detection. We are only focused on the disruptive critical voltage (dielectric strength) as it dictates the required voltages to form a spark between two (2) conductive points.

To allow electricity (energy stored as charged particles) to pass through a material, the energy must pass through electrons. In metals, electrons are free to travel through the material as they are not held to any specific boundary. In the case of air, a threshold must be reached before electrons are able to “move”. This threshold is defined as the dielectric strength. Once the voltage is greater than the dielectric strength of air, air becomes electrically conductive in which electrons have enough energy to collide into each other producing a pathway for discharge. Once a discharge is produced, an audible and visible spark can be generated (Figure 1).



Figure 1: Examples of Voltage Exceeding Dielectric Strength of Air and Generating a Visible Spark

It is commonly stated that the dielectric strength of air is approximately 3MV/m which translates to 76 volts per mil. Its exact value varies with the shape and size of the electrodes and increases with the pressure of the air. Humidity has been proven to not be a factor effecting the critical voltage for discharge. Although, any solids or liquid contained in the air (smoke, rain, snow, dust, etc.) has a pronounced impact on the voltage thresholds. Contamination of conductive particles have shown reduction in the dielectric strength of air by up to 10% [3]. The trend of air's dielectric strength has been shown to be linear or close to at larger distances.

For distances less than a meter, Paschen's Law is used to define the breakdown voltages for gases as a linear assumption is not adequate. In 1889, Friedrich Paschen discovered the relationship between breakdown voltage (dielectric strength) and gap length between electrodes. This relationship was used to produce the Paschen's Law. The Paschen's law defines that a minimum of approximately 340 volts are required no matter the distance of air gap. A plot displaying Paschen's Law versus distance can be seen in Figure 2.

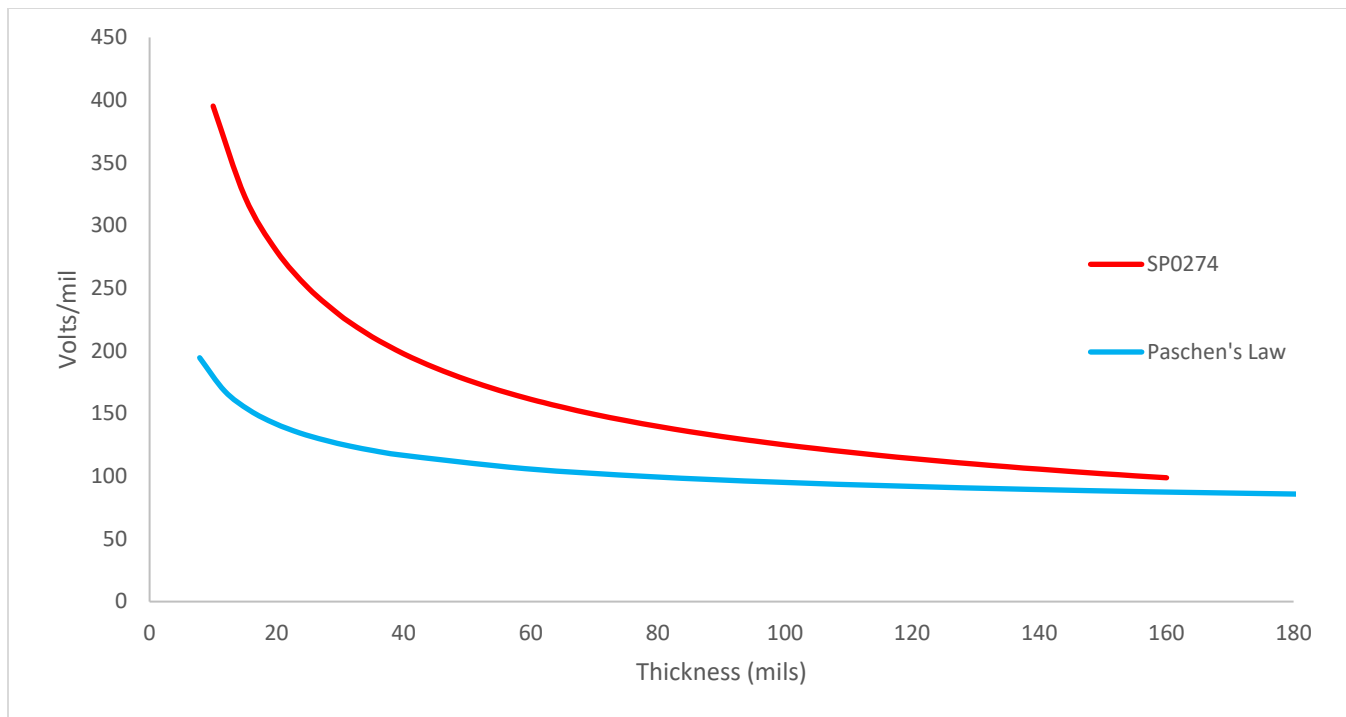


Figure 2: Trend of Paschen's Law and NACE SP0274 Equation

It is assumed that the dielectric strength of air and holiday detection is independent of the type of coating used as the coating's barrier properties do not influence the spark or air properties.

Dielectric Strength of Coatings

The dielectric strength of a material can be defined as the maximum electric pulse or field that a material can withstand before breakdown. As cautioned by most coating manufacturers and stated within the industry standards, care should be taken to prevent exceeding the dielectric breakdown voltage when performing high voltage holiday detection. If too high a voltage is applied the coating system, it can be electrically burned and can adversely affecting the resin (binder) properties. ASTM¹ D149 [4] is a common laboratory test used to determine a dielectric breakdown voltage of a protective coating or lining.

The dielectric strength of most high-quality protective coatings and linings used for chemical containment or immersion service generally exceed 500 volts per mil, many of which are greater than 1000 volts per mil, when tested in accordance with ASTM D149.

Damaging a high dielectric coating by exposure to excessive voltage when following industry consensus standards is not likely.

Industry Consensus Standards

There are several industry consensus standards developed specifically for high voltage holiday testing on conductive substrates. Common standards used in North America include:

- NACE² SP0188 *Standard Practice for Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates* [5]
- NACE SP0274 *Standard Practice for High-Voltage Electrical Inspection of Pipeline Coatings* [6]
- NACE SP0490 *Holiday Detection of Fusion-Bonded Epoxy External Pipeline Coating of 250 to 760 μ m (10 to 30 mil)* [7]

¹ ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428, USA

² AMPP (Formerly NACE International (NACE)), 15835 Ten Place, Houston, TX 77084, USA

- ASTM G62 *Standard Test Method for Holiday Testing in Pipeline Coatings* [8]
- ASTM D4787 *Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates* [9]
- ASTM D5162 *Standard Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates* [10]

Although these standards vary slightly, the majority reference Equation 1 below as the basis for the voltage setting.

$$\text{Testing Voltage} = 1250\sqrt{t} \quad (1)$$

where t = coating thickness in mils.

For some of these standards the voltage setting drops below the 100 volts per mil based on coating thickness, although the thickness threshold varies from standard to standard (denoted red in Table 1). A summary of the most commonly referenced standards are shown in Table 1 and Figure 3.

The voltage settings by industry standard vary significantly based on coating thickness. It is important to ensure that the voltage is high enough to break the air gap equivalent to the highest coating thickness [5,8,9,10].

To the authors knowledge, there are no reported resources to confirm the validity of these industry standards and their recommended voltage settings. There are a number of research papers that publish similar trends to that of equation (1) stated in NACE SP0274 but the origin of the equation is unknown. To assess the validity of these standards and the 100 volts per mil “rule of thumb”, an experimental procedure was put together.

Table 1: Voltage Setting Recommendations by Dry Film Thickness for Various Standards

High-Voltage Holiday Testing Standards, V/mil								
DFT (mils)	NACE SP0188	NACE SP0274		NACE SP0490	ASTM D5162		ASTM G62	
		Formula Method	Chart Method		Formula Method	Chart Method	Formula Method	Dielectric Method
12	167	N/R	N/R	165	152	N/R	152	Determine V/mil setting using ASTM D149 to determine dielectric breakdown voltage and multiply by minimum allowable coating thickness
16	156			131	131		131	
20	125	300	280	118	117	135	117	
25	120	250	240	106	105	132	105	
30	100	228	233	97	96	130	96	
35	86	211	200	N/R	89	129	89	
40	75	198	175		198	138	83	
45	89	187	156		186	133	187	
50	80	177	140		177	130	177	
55	73	169	127		169	136	169	
60	100	161	117		161	133	161	
65	92	155	154		155	131	155	
70	86	149	142		149	129	149	
75	80	144	133		144	144	144	
80	75	140	125		140	144	140	
85	118	136	118		136	141	136	
90	111	132	111		132	139	132	
95	105	128	126		128	142	128	
100	100	125	120		125	140	125	
110	91	119	109		119	141	119	
120	83	114	100		114	138	114	
130	115	110	108		110	138	110	
140	107	106	100		106	136	106	
150	100	102	93		102	140	102	
160	94	99	100		99	141	99	

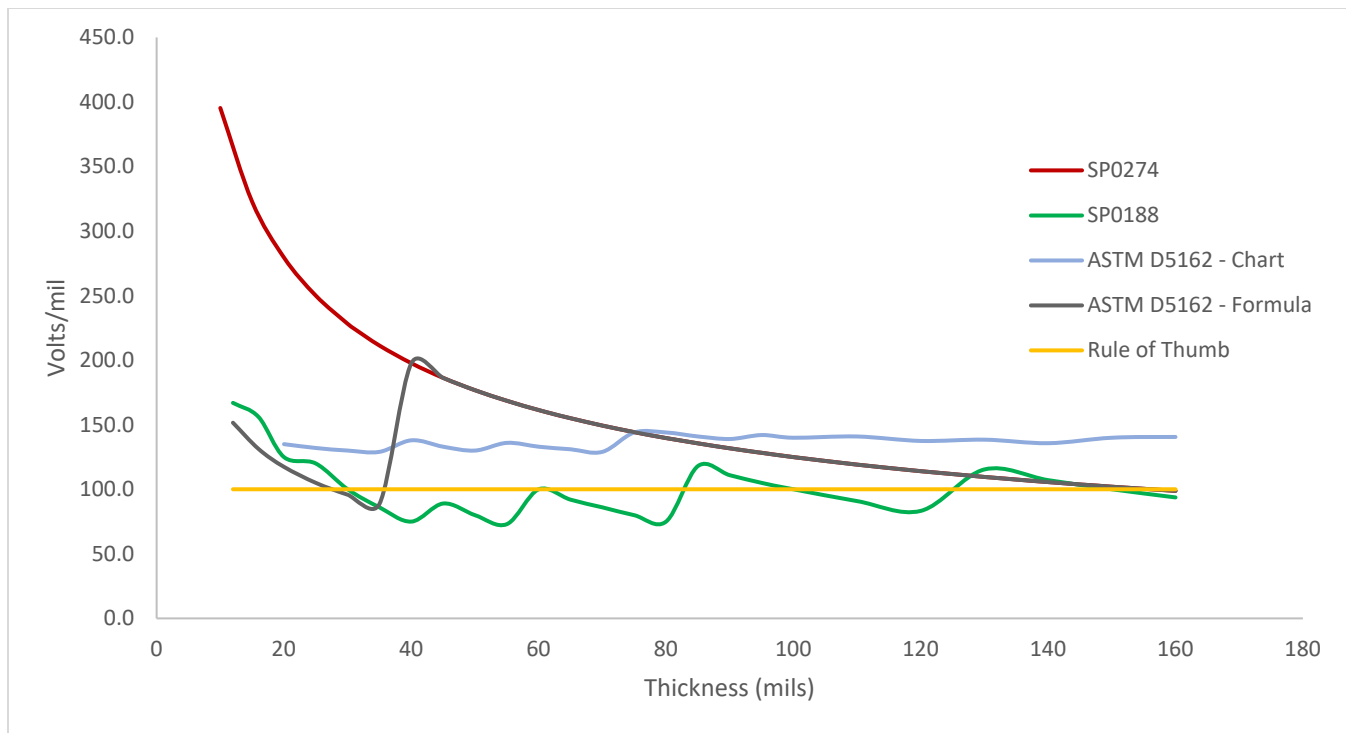


Figure 3: Industry Standards Recommended Voltage Settings

EXPERIMENTAL PROCEDURE

There is a need for a more comprehensive understanding of the voltage setting required to consistently locate holidays in a protective coating. The objective of this study is to present information used to determine the probability of holiday detection at different voltages at varying coating thicknesses.

Test specimens

Ten (10) carbon steel panels measuring 2-ft x 2-ft x 1/8-in were abrasive blasted to a SSPC-SP10/NACE No. 2 (10) with a minimum 3.0 mil angular anchor profile and coated with a 100 percent volume solids epoxy coating at various thicknesses (Figure 4). The epoxy coating used has a dielectric strength of 618 volts/mil when tested per ASTM D149. The panels were designed for coating thicknesses between 10 and 160 mils with slight variability allowed due to practical coating application. The panels average thicknesses are as follows:

Table 2: Testing Panel Coating Thicknesses

Panel #	Coating Dry Film Thickness (DFT)
1	12.1 mils
2	21.4 mils
3	33.4 mils
4	43.1 mils
5	61.2 mils
6	78.2 mils
7	101.5 mils
8	123.3 mils
9	141.1 mils
10	159.9 mils

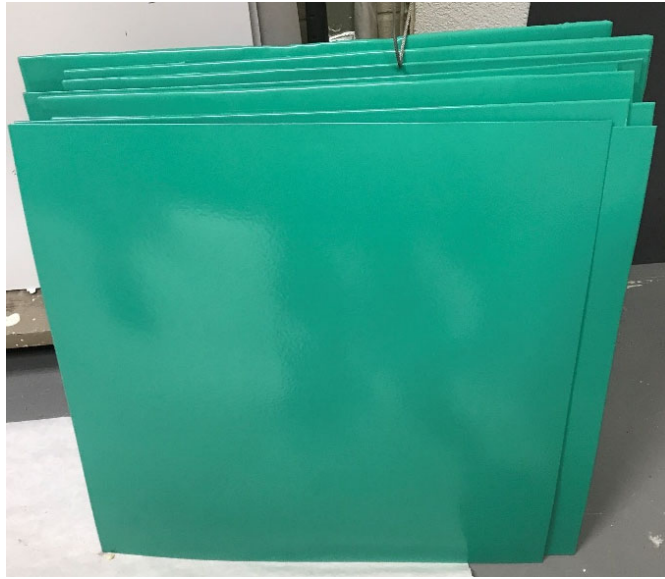


Figure 4: Ten Test Panels

Each test panel was divided into segments and six (6) artificial holiday locations were designated and marked accordingly. The average of three dry film thickness measurements were performed at each holiday location (Figure 5) using a calibrated Type 2 electronic dry film thickness gauge.

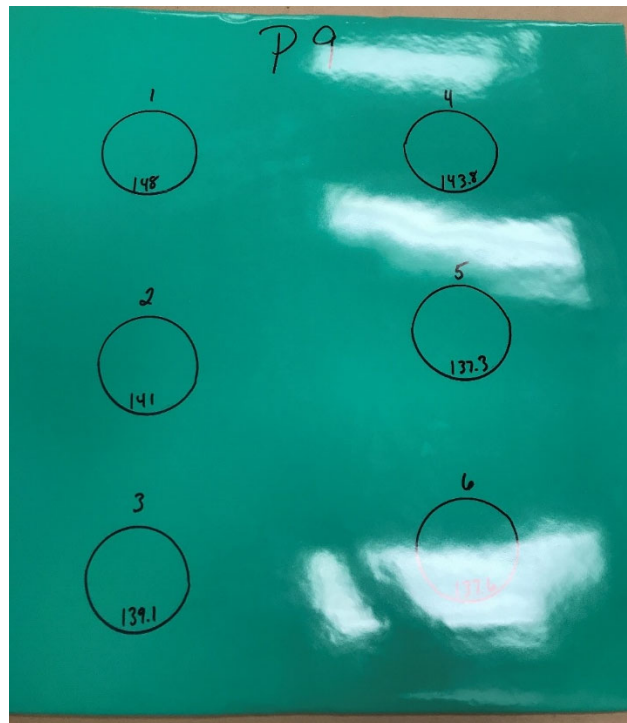


Figure 5: Example of Coated Steel Panel with Six Artificial Holiday Locations with DFT Measurements (mils)