HIGH VOLTAGE POROSITY TESTING CONTINUOUS DC vs. PULSED DC

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Abstract: In certain protective coating applications, it is vital to test the finished system for flaws and pinholes, as these defects can lead to premature coating failure in service. This is particularly important when the coating is used in an immersion or partial immersion situation such as for tank or pipe linings.

The main technique used for porosity testing of protective coatings is the high voltage test where a probe with a voltage, measured in kilovolts (kV,) is applied to the coating and detections of a flaw results in a flow of current, which can be used to create an alarm.

The two ASTM documents for porosity or discontinuity detection, D 5162 for testing coatings on metal substrate and D 4787 for testing for coatings on concrete, both mention continuous DC and pulsed DC apparatus. The NACE recommended practise, SP 0188, also refers to these two test method.

This paper will discuss these two types of equipment and compare and contrast their use and performance.

Introduction

Acceptance testing for coatings applied as protection for buried pipelines or for tanks usually includes porosity testing. Porosity testing in coatings is often referred to as holiday detection and can be carried out using either low voltage (wet sponge testing) or high voltage testing.

Holiday detection using the wet sponge method is restricted to coatings that are up to 500 µm (20 mil) thick. The wet sponge detectors will only alarm when the sponge electrode is passed over a pinhole, which penetrates right through the coating to the substrate. This method will not be discussed in this paper.

High Voltage Porosity Detection can be used to locate flaws and defects in a coating on the surface of a conductive substrate. This substrate can be metallic, steel, stainless steel, aluminium, or concrete with sufficient moisture content to make it conduct the electrical current drawn from the unit when a flaw is detected.

There are two main types of High Voltage Porosity Detector, the Continuous DC type and the Pulsed DC type. High Voltage AC (alternating current) Holiday Detectors are also available. These use the Tesla Coil discharge to a grounded surface to indicate the presence of a flaw by drawing the blue corona generated by the high AC voltage to the grounded substrate. However, surface contaminants and moisture content can also cause a spark and the high AC voltage is hazardous and can more easily cause severe electrical shocks in us.

This paper will discuss the operation and use of the Continuous DC and Pulsed DC High Voltage Porosity Detectors. The difference between Pulsed DC and AC is the fact that the pulsed DC voltage changes from zero volts to the test voltage and back to zero many times per second whereas the AC voltage changes from the test voltage in both positive and negative swings at the frequency of the mains voltage 60 Hz in the USA or 50 Hz in Europe.

Flaws and Defects

Coating 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 pipe or a tank. There are many cause that can be attributed to coating defects and some of the more common flaws which result in porosity or holidays in a coating include runs and sags, pinholes, cratering, cissing and the wrong coating thickness.

Runs and sags are caused by excessive local coating thickness while pinholes are often caused by air or blast media trapped in the coating during its application. Cratering is the result of air release from the surface of the coating at the point in the process where the coating is partially cured and the coating does not flow back to cover the void created by the release of the air. Cissing is also known as crawling or fisheyes and is characterised by surface breaks in the coating film revealing the substrate beneath and often results from contamination of the substrate by organic materials such as oil or grease.

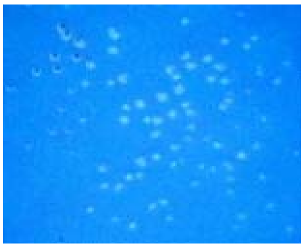
Incorrect coating thickness can be a cause of holidays when the film is either too thick or too thin. A thick coating can crack due to internal stress and a thin film can cause discontinuities, particularly when the substrate is roughened by abrasive blast cleaning.

Figure 1 shows examples of the defects described above but it should be noted that this is by no means a comprehensive list of the faults that can lead to porosity in a coating and often the defects are invisible to the naked eye. Figure 2 shows a coating thickness gauge in use.

Sags and Runs

Pinholes

Cratering



Cissing

Figure 1 – Examples of some coating defects

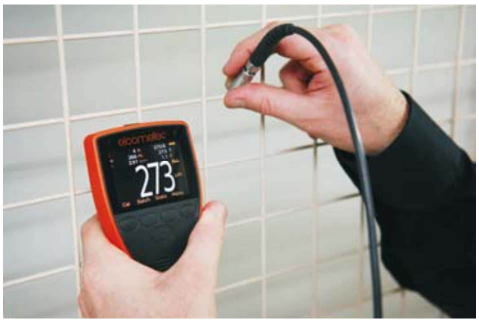


Figure 2 – Measurement of coating thickness

Standards for Porosity Detection

Many of the International Standard Societies publish standards that cover the use of high voltage holiday detectors for coatings, including NACE, ASTM and ISO.

NACE – The National Association of Corrosion Engineers (NACE International) standard SP0188: 2006 “Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates”, provides a procedure for electrical detection of minute discontinuities in coating systems that are liquid-applied to conductive substrates other than pipelines.

Section 4 of this standard describes the use of high voltage spark testing and it defines the high voltage as being in excess of 800 V. The test voltage is suggested according to the thickness of the coating in bands as shown in table 1.

Total Dry Film Thickness		**Suggested Voltage (V)**
(µm)	(mil)	
200 to 300	8 to 11	1,500
300 to 400	12 to 15	2,000
400 to 500	16 to 20	2,500
500 to 1,000	21 to 40	3,000
1,000 to 1,400	41 to 55	4,000
1,400 to 2,000	56 to 80	6,000
2,000 to 3,200	81 to 125	10,000
3,200 to 4,700	126 to 185	15,000

Table 1 Suggested Voltages for High-Voltage Spark Testing according to NACE SP0188

NACE RP0274:2004 High Voltage Electrical Inspection of Pipeline Coatings refers to both DC and Pulsed DC detectors and defines pulse-type detectors as having high voltage pulses of very short duration, e.g. 0.0002 seconds at a rate of 30 pulses per second.

The recommendations in the standard do not apply to thin-film coatings (i.e. coating materials usually applied by a fusion bonding process. It is noted that thin-film pipeline coatings are generally applied to a dry film thickness less than 0.5 mm (20 mil).)

The determination of the test voltage is given in section 3 and shall be within 20% of the value determined from either of the equations below or from the values shown in table 2.

The equations have two forms, one for thickness in metric units (mm) and one for thickness in imperial (English) units (mil) as follows:

$$V = 7{,}900\sqrt{T}$$

Where: V = test voltage and T is the thickness in mm

$$V = 1{,}250\sqrt{T}$$

Where: V = test voltage and T is the thickness in mil

Coating Thickness		**Testing Voltage (V)**
(mm)	(mils)	
0.51	20	6,000
0.79	31	7,000
1.6	62	10,000
2.4	94	12,000
3.2	125	14,000
4.0	156	16,000
4.8	188	17,000
13	500	28,000
16	625	31,000
19	750	34,000

Table 2 Minimum Testing Voltage for Various Coating Thicknesses
From NACE RP0274

NACE SP0490-2007, Holiday Detection of Fusion-Bonded Epoxy External Coatings of 250 to 760 µm (10 to 30 mil) also describes both Continuous DC and Pulsed DC Holiday Detectors and also gives both a formula and voltage table approach to selecting the test voltage based on the thickness of the coating.

The equations have two forms, one for thickness in metric units (µm) and one for thickness in imperial (English) units (mil) as follows:

$$V = 104\sqrt{T}$$

Where: V = test voltage and T is the thickness in µm

$$V = 525\sqrt{T}$$

Where: V = test voltage and T is the thickness in mil

Table 3 below shows the recommended test voltages for various thickness values.

Coating Thickness	Test Voltage (V)
250 µm (10 mil)	1,650
280 µm (11 mil)	1,750
300 µm (12 mil)	1,800
330 µm (13 mil)	1,900
360 µm (14 mil)	1,950
380 µm (15 mil)	2,050
410 µm (16 mil)	2,100
510 µm (20 mil)	2,350
640 µm (25 mil)	2,650
760 µm (30 mil)	2,900

Table 3 Recommended Test Voltages for Various FBE Coating Thicknesses
From NACE SP0490 - 2007

ASTM - There are several documents covering discontinuity (holiday) detection published by ASTM International, but subcommittee D01.48 has now withdrawn the Test Method for Holiday Detection in Pipeline Coatings, G 62.

It should be noted that under ASTM rules, test methods require round robin testing and practises do not. A round robin test for holiday detection in pipeline coatings will be very difficult to arrange and complete. For this reason, it is likely that this test method has been withdrawn in favour of a practise.

Subcommittee 01.46, Industrial Protective Coatings, has the stewardship of D5162, Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates and this practice was reviewed and balloted for re-approval in 2007. The current version of this practise was published in 2008.

It should be noted that there is also a standard practise, D4787, entitled "Continuity verification for liquid or sheet linings applied to concrete substrates", which covers testing for discontinuities in coatings on concrete using both the low-voltage wet sponge and the high-voltage spark test methods. This practise was also revised in 2007 by subcommittee 01.46 and balloted for re-approval and published in 2008.

Theses standards describe two methods for the selection of the test voltage, a table of voltage values dependant on bands of thickness values or a formula. Table 4 shows the table contained in D4787. The voltage is shown in kV to be consistent within this paper, as the table in D4787 shows the suggested voltage in volts (V).

The formula given in D4787 is reproduced below:

$$V = M\sqrt{Tc}$$

Where *V* = the test voltage
Tc = the coating or lining thickness
M = a constant depending on the thickness range and the units of thickness

Coating Thickness Units	Coating Thickness Range	Constant Value (M)
mm	< 1.00 (1,000 µm)	3,294
mm	> 1.00 (1,000 µm)	7,843
mil	< 40.0	525
mil	> 40.0	1,250

For example:

For a coating of 500 µm thickness, *Tc* = 0.5 and *M* = 3,294, therefore

$$V = 3294\sqrt{0.5}$$

$$V = 3294 \text{ x } 0.707$$

$$V = 2{,}329 \text{ V } (2.33 \text{ kV})$$

For a coating of 20 mil thickness, *Tc* = 20 and *M* = 525, therefore

$$V = 525\sqrt{20}$$

$$V = 525 \text{ x } 4.472$$

$$V = 2{,}347 \text{ V } (2.34 \text{ kV})$$

NOTE: For a coating of 500 µm (20 mil) thickness, the table gives a suggested inspection voltage of 2.70 kV, which is slightly higher than the formula but only by 360 or 370 V depending on the thickness units.

For a coating of 1,500 µm thickness, Tc = 1.5 and M = 7,843, therefore

$$V = 7843\sqrt{1.5}$$

$$V = 7843 \text{ x } 1.224$$

$$V = 9{,}599 \text{ V } (9.60 \text{ kV})$$

For a coating of 60 mil thickness, Tc = 60 and M = 1,250, therefore

$$V = 1250\sqrt{60}$$

$$V = 1250 \text{ x } 7.745$$

$$V = 9{,}681 \text{ V } (9.68 \text{ kV})$$

Total Dry Film Thickness		Suggested Inspection Voltage (kV)
mm	mils	
0.500–0.590	19.7–23.2	2.7
0.600–0.690	23.6–27.2	3.3
0.700–0.790	27.6–31.1	3.9
0.800–0.890	31.5–35.0	4.5
0.900–0.990	35.4–39.0	5.0
1.000–1.090	39.4–42.9	5.5
1.100–1.190	43.3–46.9	6.0
1.200–1.290	47.2–50.8	6.5
1.300–1.390	51.2–54.7	7.0
1.400–1.490	55.1–58.7	7.5
1.500–1.590	59.1–62.6	8.0
1.600–1.690	63.0–66.5	8.5
1.700–1.790	66.9–70.5	9.0
1.800–1.890	70.9–74.4	10.0
1.900–1.990	74.8–78.3	10.8
2.000–2.090	78.7–82.3	11.5
2.100–2.190	82.7–86.2	12.0
2.200–2.290	86.6–90.2	12.5
2.300–2.390	90.6–94.1	13.0
2.400–2.490	94.5–98.0	13.5
2.500–2.590	98.4–102.0	14.0
2.600–2.690	102.4–105.9	14.5
2.700–2.790	106.3–109.8	15.0
2.800–2.890	110.2–113.8	15.5
2.900–2.990	114.2–117.7	16.0
3.000–3.090	118.1–121.7	16.5
3.100–3.190	122.0–125.6	17.0
3.200–3.290	126.0–129.5	17.5
3.300–3.390	129.9–133.5	18.0
3.400–3.490	133.9–137.4	18.5
3.500–3.590	137.8–141.3	19.0
3.600–3.690	141.7–145.3	19.5
3.700–3.790	145.7–149.2	20.0
3.800–3.890	149.6–153.1	21.0
3.900–3.990	153.5–157.1	21.8
4.000–4.190	157.5–165.0	22.5
4.200–4.290	165.4–168.9	23.0
4.300–4.390	169.3–172.8	24.0
4.400–4.490	173.2–176.8	25.0
4.500–4.590	177.2–180.7	25.8
4.600–4.690	181.1–184.6	26.4
4.700–4.790	185.0–188.6	26.8
4.800–4.890	189.0–192.5	27.4
4.900–4.990	192.9–196.5	28.0
5.000–5.290	196.9–208.3	28.5
5.300–5.500	208.7–216.5	29.0
5.600–8.000	220.5–307.1	30.0

Table 4 Suggested Voltages for High Voltage Spark Testing

ISO – The International Standards Organisation has published a standard for porosity testing that was written by a technical committee within the European Standards Organisation (CEN). The draft document was subjected to a parallel voting procedure by both CEN and ISO.

Mean Dry Film Thickness (µm)	**Test Voltage (kV)**
up to 500	2,3
above 500 but < 600	2,9
above 600 but < 700	3,5
above 700 but < 800	4,0
above 800 but < 900	4,5
above 900 but < 1,000	5,0
above 1,000 but < 1,100	5,5
above 1,100 but < 1,200	6,5
above 1,200 but < 1,300	7,0
above 1,300 but < 1,400	7.5
above 1,400 but < 1,500	8,0
above 1,500 but < 1,600	8.5
above 1,600 but < 1,700	9.0
above 1,700 but < 1,800	10.0
above 1,800 but < 1,900	10.5
above 1,900 but < 2,000	11.0
above 2,000 but < 2,100	11.7
above 2,100 but < 2,200	12.4
above 2,200 but < 2,300	13.0
above 2,300 but < 2,400	13.5
above 2,400 but < 2,500	14.0
above 2,500 but < 2,600	14.5
above 2,600 but < 2,700	15.0
above 2,700 but < 2,800	15.5
above 2,800 but < 2,900	16.0
above 2,900 but < 3,000	16.5
above 3,000 but < 3,100	17.0
above 3,100 but <3,200	17.5
above 3,200 but < 3,300	18.0
above 3,300 but < 3,400	18.5
above 3,400 but < 3,500	19.0
above 3,500 but < 3,600	19.5
above 3,600 but < 3,700	20.0
above 3,700 but < 3,800	21.0
above 3,800 but < 3,900	21.5
above 3,900 but < 4,000	22.0
above 4,000 but <4,100	22.5
above 4,100 but < 4,200	23.0
above 4,200 but < 4,300	24.0
above 4,300 but < 4,400	25.0
above 4,400 but < 4,500	25.8
above 4,500 but < 4,600	26.4
above 4,600 but < 4,700	26.8
above 4,700 but < 4,800	27.4
above 4,800 but < 4,900	28.0
above 4,900 but < 5,000	28.5
above 5,000 but < 5,300	29.0
above 5,300 but < 8,000	30.0

Table 5 Voltages for High Voltage Spark Testing from BS EN ISO 29601

This standard is BS EN ISO 29601 and it was published in the first half of 2011. This standard is entitled “Paints and varnishes – Corrosion protection by protective paint systems – Assessment of porosity in a dry film” and also describes the low-voltage (wet sponge) method and the high voltage spark tester.

Table 4 shows the test voltages for mean dry film thickness values and takes account of the need to have sufficient voltage to overcome the breakdown voltage of air in a flaw, which is typically 4 kV/mm.

The breakdown voltage for air varies with the temperature, pressure and moisture content of the air but these variations will not be significant in practise. More significant is the dielectric strength of the coating which can be in the range 6 kV/mm to 20 kV/mm depending on the formulation of the coating. The effect of this is to make it critical that for testing coatings of low dielectric strength the test voltage is not set too high so that the risk of over-testing and possibly burning a hole in the coating is avoided.

To ensure that the voltage is sufficient to achieve breakdown of the air but not too high to cause damage thickness bands have been chosen to avoid a single test voltage value being applied to a wide range of thickness. If the coating has a relatively high dielectric strength then the selection of the test voltage is less critical as the risk of damaging the coating is much reduced.

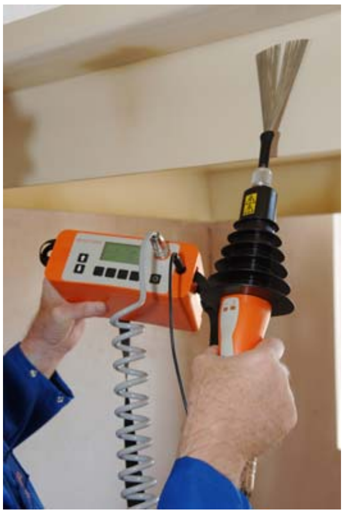
For paint systems with a mean dry film thickness of up to 500 µm, low-voltage pinhole detectors shall normally be used. A high-voltage spark tester may, however, be used to test a paint system with a mean dry film thickness less than 500 µm, but not less than 300 µm, by agreement between the interested parties. For paint systems with a mean dry film thickness greater than 500 µm, high-voltage spark testers shall be used.

Continuous DC High Voltage Testing

Continuous DC High Voltage Testing requires a signal return cable to be electrically connected between the conductive substrate and the high voltage test unit so that the current that flows from the high voltage electrode when a flaw is detected can flow through the alarm circuit to indicate to the operator that a flaw has been detected.

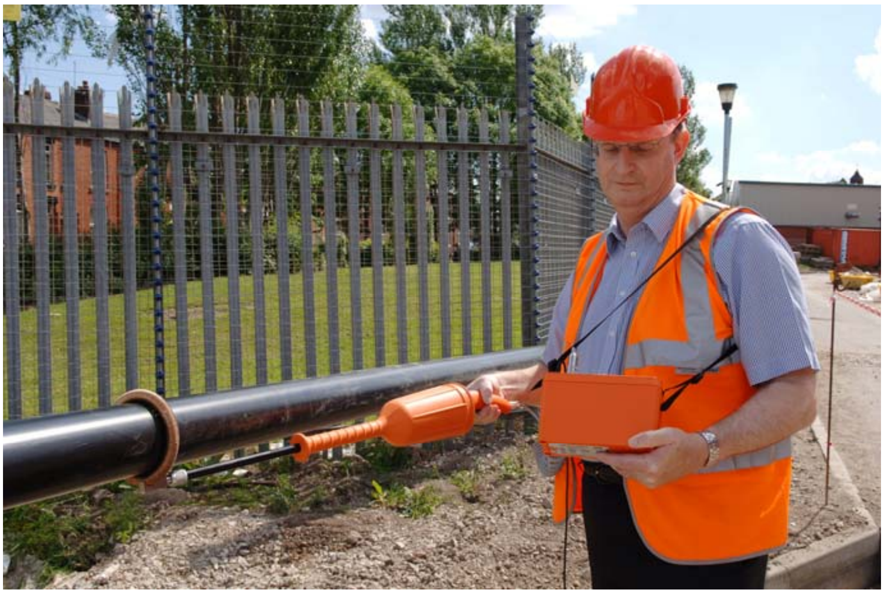
A range of electrode styles has been developed to help the operator apply the voltage to the coated substrate. The electrode supplied as standard is the “Band Brush” probe which is excellent for locating the position of a flaw in the coating. At test voltages above 5 kV the spark can be easily seen and hence the flaw located. At lower voltages or in bright sunlight the spark might not be so easy to see and the narrow shape of the brush allows the flaw to be located with precision by only applying a small section of the brush in the area of the flaw until it passes over the defect.

For the design shown in the illustration, the high voltage is generated in the probe handle and the base unit provides the low voltage power supply to the handle from a rechargeable lithium ion battery, making the unit fully portable. Three different handles are available for different test voltage ranges, 0.5 to 5 kV, 0.5 to 15 kV and 0.5 to 30 kV. This also helps to prevent over testing with too high a test voltage. For example, if the coatings to be tested are always less than 1,000 µm (40 mil) thick then the 0.5 to 5 kV handle is the appropriate choice as over testing at 15 kV or 30 kV would not be possible.



A Continuous DC High Voltage Porosity Detector
Being Used with a Band Brush Probe on a Coated Beam

Other electrode styles include wide wire brushes, internal pipe brushes, external rolling spring electrodes for pipes and conductive rubber strips for soft coatings that may be scratched by the wire type electrodes.

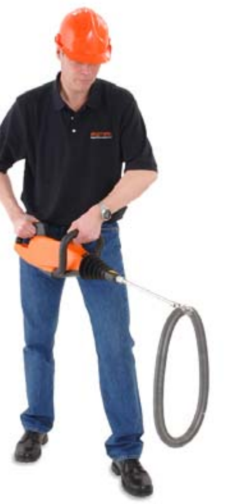


The Rolling Spring Electrode in Use on a 150 mm Diameter Pipe
The High Voltage Handle is fitted with an Insulated Second Handle to Aid Handling

The test voltage can either be set by adjusting the value shown in the base unit display up or down until the selected voltage is displayed or the calculation feature can be used by selecting the standard to which to coating is to be tested from a menu list and then entering the value of the thickness for the coating. The detector will then calculate and set the test voltage based on the standard selected.

<u>Pulsed DC High Voltage Testing</u>

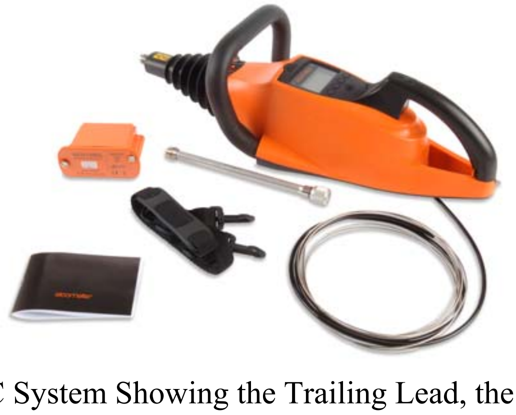
The new design of Pulsed DC High Voltage Holiday Detector allows coatings to be tested using a training signal return cable that lies on the surface of the coating and provides a capacitive signal path if a flaw is located by the high voltage electrode.



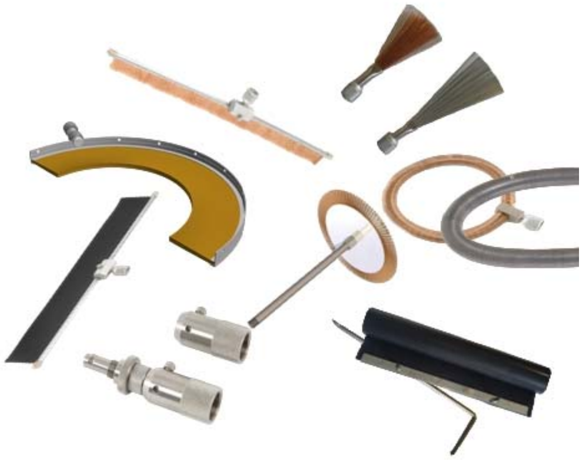
The Pulsed DC High Voltage Holiday Detector
Showing a Rolling Spring Electrode Ready to Wrap Round a Pipe.

The trailing signal return cable is able to operate because the Pulsed DC test voltage is changing, rising from zero volts to the pre-set test voltage, several kV, 30 times per second. This changing voltage means that a capacitor in the circuit will charge and discharge allowing current to flow. This is not the case with the Continuous DC power supply. A training lead on top of the coating will create a capacitor between the conductive substrate and the un-insulated cable conductor with the insulating coating acting and the dielectric in the capacitor.

It is also the case that the energy in the Pulsed DC system is contained within the short duration pulses and therefore the test voltage can be maintained on a slightly conductive coating. The system is monitoring for a significant release of energy through a flaw and can ignore the lower energy released by dirt or moisture on the coating. The alarm circuit is set to ignore these stray currents and only react to the significant pulses of energy in the signal return cable.



A Pulsed DC System Showing the Trailing Lead, the Battery Pack
The Extension Piece, the Shoulder Strap and the Operating Instruction



An array of High Voltage Test Electrodes
Including Band Brushes, Rolling Spring, Straight and Curved Wire Brushes, Conductive Rubber and Internal Brush Types. These can be used with either Continuous DC or Pulsed DC High Voltage Porosity Detectors.

It should be noted that the capacitive effect that provides the connection through the trailing lead also has an influence on the choice of test electrodes. The capacitive loading of a particular electrode design is affected by the size of the electrode and the thickness of the coating to be tested. In some cases, a large electrode on a thin coating can provide a significant capacitive loading to the pulsed high-voltage power supply making it appear that the electrode is constantly finding flaws. A smaller electrode will normally solve this problem.

Conclusions

The key to successful testing for holidays in non-conductive cured coating systems is the selection of the test voltage.

Each of the standards, NACE, ASTM and ISO, provide either a method for calculating the test voltage or selecting the test voltage from a table, based on the thickness of the coating to be measured. It must be noted that variations in thickness may cause defects to be detected, either as a result of the coating being too thin and therefore not providing sufficient electrical strength to prevent sparking to the substrate or by causing defects such as runs and sags when the coating is too thick.

Particular care must be taken when the dielectric strength of the coating is low, as too high a test voltage may cause the coating to burn and create a defect where no defect existed before the testing. This has to be managed by careful selection of the test voltage based on detailed knowledge of the coating thickness.

The selection between the Continuous DC and the Pulsed DC method is often one based on practical issues. If the item to be tested has been coated so that not bare metal is available to connect the signal return cable then the Pulsed DC method using the trailing lead signal return is indicated. However, it must be recognised that a good conductive connection is not guaranteed and there is a risk that flaws, particularly small defects may be missed if this method is used.

If the testing is to be carried out at a specific test voltage with high accuracy then the Continuous DC method is indicated as the measurement of a continuous voltage is easier and more accurate than for a pulsed voltage. Again it must be recognised that for reasons of safety in respect of the high voltage the Continuous DC unit have power supplies that reduce the output voltage when current is drawn as it is the flow of current that is dangerous in high voltage testing. To accurately measure the output voltage a very high impedance voltmeter is required so that minimal current is drawn during the test thus keeping the output voltage close to its set value. Once current flows the high voltage test is over and a flaw or defect has been detected. The electrode has to be moved away from the defect to re-establish the test voltage and continue the testing.

There are some differences in the test voltage values given by the different standards and even for the different methods for determining the test voltage within the standards.

For a coating of 500 µm (20 mil) the following voltages are suggested or recommended:

NACE SP0188	2.5 kV
NACE RP0274	6.0 kV
NACE SP0490	2.3 kV
ASTM D4787	2.33 kV (or 2.7 kV if the table is used)
BS EN ISO 29601	2.90 kV

Therefore to avoid over testing a particular coating care must be taken when specifying a high voltage test and the electrical strength of the coating must be taken in to account.

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