

Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems

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ABSTRACT

This standard test method provides descriptions of the measurement techniques and cautionary measures most commonly used on underground and submerged piping other than offshore piping to determine whether a specific criterion has been met at a test site. This standard contains instrumentation and general measurement guidelines. It includes methods for voltage drop considerations when structure-to-electrolyte potential measurements are made and provides guidance to minimize incorrect data from being collected and used. This standard is maintained by Task Group 020.

KEYWORDS

pipelines, test methods, underground piping, submerged piping

Foreword

In NACE standards, the terms “shall,” “must,” “should,” and “may” are used in accordance with the definitions of these terms in the NACE Publications Style Manual. The terms “shall” and “must” are used to state a requirement, and are considered mandatory. The term “should” is used to state something good and is recommended, but is not considered mandatory. The term “may” is used to state something considered optional.

This NACE International standard test method provides descriptions of the measurement techniques and cautionary measures most commonly used on underground and submerged piping other than offshore piping to determine whether one or more selected criterion has been met at a representative test site(s) with consideration for special conditions. These methods are also applicable to many other underground or submerged metallic structures. Descriptions of measurement techniques and cautionary measures used on offshore pipelines and structures can be found in NACE SP0115/ISO 15589-2 for offshore pipelines and SP0176 for offshore structures.^{1,2} This standard includes only those measurement techniques that relate to the criteria or special conditions, such as a net protective current and alternating current (AC) corrosion testing.³ This standard is intended for use by corrosion control personnel concerned with the corrosion of underground or submerged piping systems that transport oil, gas, water, or other fluids.

The measurement techniques described require that the measurements be made in the field. Because the measurements are obtained under widely varying circumstances of field conditions and pipeline design, this standard is not as prescriptive as those NACE standard test methods that use laboratory measurements. Instead, this standard gives the user latitude to make testing decisions in the field based on the technical facts available.

This standard contains instrumentation and general measurement guidelines. It includes methods for voltage drop considerations when structure-to-electrolyte potential measurements are made and provides guidance to minimize incorrect data from being collected and used.

The measurement techniques provided in this standard were compiled from information submitted by committee members and others with expertise on the subject. Variations or other techniques not included may be equally effective. The complexity and diversity of environmental conditions may require the use of other techniques.

Appendix A (mandatory) contains information on the common types, use, and maintenance of reference electrodes. Appendix B (nonmandatory) contains information for direct current (DC) Cell-to-Cell Surface Potential Gradient Surveys. Appendix C (nonmandatory) contains information regarding the use of coupons to evaluate cathodic protection (CP), Appendix D (nonmandatory) contains information regarding Dynamic Stray Current testing, Appendix E (nonmandatory) contains information regarding AC Corrosion testing and Appendix F (nonmandatory) contains information regarding Evaluation of Potentials Considering Adequacy of Current Interruption. As there is ongoing research into the nonmandatory procedures, the tester is advised to keep abreast of any revisions or improvements.

The test methods in this standard were originally prepared by NACE Task Group (TG) T-10A-3, “Test Methods and Measurement Techniques Related to Cathodic Protection Criteria,” a component of Unit Committee T-10A, “Cathodic Protection,” in 1994. It was reviewed /revised by TG 020, “Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems,” which is administered by Specific Technology Group (STG) 35, “Pipelines, Tanks, and Well Casings,” and is sponsored by STG 05, “Cathodic/Anodic Protection.” It was reaffirmed in 2002 by STG 35 and revised in 2012 and 2018 by TG 020. This standard is issued by NACE under the auspices of STG 35.

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Section 1: General

- 1.1 This standard describes and illustrates testing procedures for measuring potentials that are used to determine whether a CP criterion is achieved at a test site on underground or submerged metallic piping systems.
- 1.2 The provisions of this standard shall be applied by personnel who have the knowledge and understanding of the fundamentals of cathodic protection of buried and submerged metallic piping systems acquired by education and related practical experience.
- 1.3 Special conditions in which a given test technique is ineffective or only partially effective sometimes exist. Refer to Paragraphs 5.9 and 6.1. Deviation from this standard may be warranted in specific situations.

Section 2: Definitions⁽¹⁾ and Acronyms

2.1 Definitions

Anode: The electrode of an electrochemical cell at which oxidation occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter the solution at the anode.

Cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. Electrons flow toward the cathode in the external circuit.

Cathodic Polarization: The change of electrode potential in the active (negative) direction caused by current across the electrode/electrolyte interface. See *Polarization*.

Cathodic Protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Cathodic Protection Coupon: A metal sample representing the pipeline at the test site, used for cathodic protection testing, and having a chemical composition approximating that of the pipe. The coupon size should be small to avoid excessive current drain on the cathodic protection system.

Close-Interval Potential Survey (CIPS): A series of structure-to-electrolyte direct current (DC) potential measurements performed at regularly spaced intervals for assessing the level of cathodic protection (CP) on pipelines and other buried or submerged metallic structures.

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. Coatings used in conjunction with cathodic protection are electrically isolating materials applied to the surface of the metallic structure that provides an adherent film that isolates the metallic structure from the surrounding electrolyte. The thickness and structure of the coating type vary according to the environment and application parameters.

Conductor: A bare or insulated material suitable for carrying electric current.

Corrosion: The deterioration of a material, usually a metal, that results from a reaction with its environment.

⁽¹⁾ Definitions in this section reflect common usage among practicing corrosion control personnel and apply specifically to how terms are used in this standard. As much as possible, these definitions are in accord with those in NACE/ASTM G193.⁴

Corrosion Potential (E_{corr}): The potential of a corroding surface in an electrolyte relative to a reference electrode under open-circuit conditions (also known as *Rest Potential*, *Open-Circuit Potential*, or *Freely Corroding Potential*).

Criterion: A standard for assessment of the effectiveness of a cathodic protection system.

Current: Electricity transfer in a conductor by (1) a flow of electric charge; (2) the amount of electric charge flowing past a specified circuit point per unit time, measured in the direction of net transport of positive charges. The direction measured with a meter is positive to negative in the conductor. (In a metallic conductor, this is the opposite to direction of electron flow. This is also called “conventional” current.)

Direct-Current Voltage Gradient (DCVG): A method of measuring the change in the electrical voltage gradient in the soil along and around the pipeline to locate and evaluate coating holidays.

Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.

Electrode: A conductor used to establish contact with an electrolyte and through which current is transferred to or from an electrolyte.

Electrode Potential: The potential of an electrode in an electrolyte as measured against a reference electrode. (The electrode potential does not include any resistance losses in potential in either the electrolyte or the external circuit. It represents the reversible work to move a unit of charge from the electrode surface through the electrolyte to the reference electrode).

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purpose of this standard, *electrolyte* refers to the soil or liquid, including contained moisture and other chemicals, next to and in contact with a buried or submerged metallic piping system.

Foreign Structure: Any metallic structure that is not intended as part of a system under cathodic protection.

Free Corrosion Potential: See *Corrosion Potential*.

Galvanic Anode: A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the current source in one type of cathodic protection.

Holiday: A discontinuity in a protective coating that exposes metallic surface to the environment.

Impressed Current: An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for cathodic protection).

Instant-OFF Potential: The polarized half-cell potential of an electrode taken immediately after the cathodic protection current is stopped, which approximates the potential without voltage drop (i.e., the polarized potential) when the current was on.

In-Line Inspection (ILI): An inspection of a pipeline from the interior of the pipe using an in-line inspection tool. Also called intelligent or smart pigging.

Interference: Any electrical disturbance on a metallic structure as a result of stray current.

Isolation: See *Electrical Isolation*.

Long-Line Current: Current through the earth between an anodic and a cathodic area that returns along an underground metallic structure.

OFF or ON: A condition whereby cathodic protection current is either turned off or on.

Parallax Error: An apparent shift in the position of a needle on an analog display, caused by a change in the observer's position that provides a new line of sight.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface.

Polarized Potential: The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

Potential Gradient: A change in the potential with respect to distance, expressed in millivolts per unit of distance.

Protection Potential: A measured potential meeting the requirements of a cathodic protection criterion.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Resistance to Electrolyte: The resistance of a structure to the surrounding electrolyte.

Reverse-Current Switch: A device that prevents the reversal of direct current through a metallic conductor.

Shielding: (1) Protecting; protective cover against mechanical damage. (2) Preventing or diverting the cathodic protection current from its natural path. For the purposes of this standard, only the second part of the definition applies.

Shorted Pipeline Casing: A metallic casing that is in electronic contact with the carrier pipe.

Side Drain Potential: A potential gradient measured between two reference electrodes, one located over the structure and the other located a specified distance lateral to the direction of the structure.

Sound Engineering Practices: Reasoning exhibited or based on thorough knowledge and experience, logically valid, and having true premises showing good judgment or sense in the application of science.

Stationary reference electrode: A reference electrode located in a fixed position previously called a permanent reference electrode.

Stray Current: Current through paths other than the intended circuit.

Structure-to-Electrolyte Potential: The potential difference between the surface of a buried or submerged metallic structure and the electrolyte that is measured with reference to an electrode in contact with the electrolyte. For the purposes of this document, this term is used in place of pipe-to-soil or pipe-to-electrolyte potential.

Telluric Current: Current in the earth that results from geomagnetic fluctuations.

Test Lead: A wire or cable attached to a structure for connection of a test instrument to make cathodic protection potential or current measurements.

Voltage: An electromotive force or a difference in electrode potentials expressed in volts.

Voltage Drop: The voltage across a resistance according to Ohm's Law.

Voltage Spiking: A momentary surging of potential that occurs on a pipeline when the protective current flow from an operating cathodic protection device is interrupted or applied. This phenomenon is the result of inductive and capacitive electrical characteristics of the system and may be incorrectly recorded as an OFF or ON structure-to-electrolyte potential measurement. This effect may last for several hundred milliseconds and is usually larger in magnitude near the connection of the cathodic protection device to the pipeline. An oscilloscope or similar instrument may be necessary to identify the magnitude and duration of the spiking.

Voltmeter: An instrument used to measure an electromotive force, or a difference in potential, in Volts. In this context any digital, analog, RMU, or fixed data logging device capable of providing voltage level measurements acceptable for the criteria being evaluated. The voltmeter used shall adhere to the equipment requirements outlined in Section 4.

Wire: A slender rod or filament of drawn metal. In practice, the term is also used for smaller gauge conductors (size 6 mm² [No. 10 AWG⁽²⁾] or smaller).

2.2 Acronyms

AC: Alternating current.

AWG: American Wire Gauge.

AGA: American Gas Association.

ANSI: American National Standards Institute.

CIPS: Close interval potential survey, also referred to as CIS.

CP: Cathodic protection.

CSE: Saturated copper-copper sulfate reference electrode.

DC: Direct current.

DCVG: Direct current voltage gradient.

ECDA: External corrosion direct assessment.

ER: Electrical Resistance.

GPS: Global Positioning System.

HIC: Hydrogen-influenced cracking.

HVAC: High-voltage alternating current.

HVDC: High voltage direct current.

⁽²⁾ American Wire Gauge (AWG).

ILI: In-line inspection.

KCL: Saturated potassium chloride reference electrode.

mV: Millivolt(s).

PDL: Portable datalogger.

PE: Polyethylene.

RF: Radio frequency.

RMU: Remote Monitor Unit.

SCC: Stress corrosion cracking.

SCE: Saturated Calomel reference electrode.

SDL: Stationary datalogger.

SHE: Standard hydrogen electrode.

SP: Standard practice.

SSC: Silver/silver chloride (Ag/AgCl) reference electrode.

Section 3: Safety Considerations

3.1 Appropriate safety precautions, including the following, shall be observed when electrical measurements are made:

3.1.1 Be knowledgeable and qualified in electrical safety precautions before installing, adjusting, repairing, removing, or testing impressed current cathodic protection equipment.

3.1.2 Use properly insulated test lead clips and terminals to avoid contact with unanticipated high voltage. Attach test clips one at a time using a single-hand technique for each connection.

3.1.3 Use caution when long test leads are extended near overhead high-voltage alternating current (HVAC) power lines, which can induce hazardous voltages onto the test leads. High-voltage direct current (HVDC) power lines do not induce voltages under normal operation, but transient conditions may cause hazardous voltages.

3.1.3.1 Refer to NACE SP0177 for additional information about electrical safety.⁵

3.1.4 Use caution when making tests at electrical isolation devices. Before proceeding with further tests, use appropriate voltage detection instruments or voltmeters with insulated test leads to determine whether hazardous voltages may exist.

3.1.5 Avoid testing when thunderstorms are in the area. Remote lightning strikes can create hazardous voltage surges that travel along the structure under test.

3.1.6 Use caution when stringing test leads across streets, roads, and other locations subject to vehicular and pedestrian traffic. When conditions warrant, use appropriate barricades, flagging, and flag persons.

3.1.7 If entry into excavations or confined spaces is required, personnel shall have the applicable training and the requirements/recommendations of all local, state and federal regulations shall be followed.

3.1.8 Observe appropriate electrical codes and applicable safety regulations.

3.1.9 Refer to NACE SP0207 and work in progress by TG 388 for additional safety considerations.^{6,7}

Section 4: Instrumentation and Measurement Guidelines

4.1 Accurate cathodic protection electrical measurements require proper selection and use of instruments. Structure-to-electrolyte potential, voltage drop, potential difference, and similar measurements require instruments that have appropriate voltage ranges. Due to the wide variety of instruments available the user must know the capabilities and limitations of the equipment, calibration of the equipment, follow the manufacturer's instruction manual, and be skilled in the use of electrical instruments. Failure to select and use instruments correctly may cause personal harm or errors in cathodic protection measurements.

4.1.1 Analog instruments are usually specified in terms of input resistance or internal resistance. This is usually expressed as ohms per volt of full meter scale deflection.

4.1.2 Digital instruments are usually specified in terms of input impedance expressed as megohms (MΩ).

4.2 Factors that may influence instrument selection for field testing include:

- (a) Analog or digital instruments;
- (b) Input impedance (digital instruments); or internal resistance (analog instruments);
- (c) Sensitivity;
- (d) Conversion speed of analog-to-digital converters used in digital or data logging instruments;
- (e) Accuracy;
- (f) Instrument resolution including sampling rates;
- (g) Ruggedness;
- (h) Alternating current (AC) and radio frequency (RF) signal rejection;
- (i) Temperature and climate limitations; and
- (j) Scales appropriate for the measurements to be made.

4.2.1 Some instruments are capable of measuring and processing voltage readings many times per second. Evaluation of the input waveform may be required if an instrument does not give consistent results.

4.2.2 Measurement of structure-to-electrolyte potentials on pipelines affected by dynamic stray currents may require the use of digital or analog recording instruments to improve measurement accuracy. Sources of AC or DC dynamic stray currents are shown in Section 5.12.3.

4.3 Instrument Effects on Voltage Measurements

4.3.1 To measure structure-to-electrolyte potentials accurately, a digital voltmeter must have a high input impedance (high internal resistance, for an analog instrument) compared with the total resistance of the measurement circuit.

4.3.1.1 A minimum input impedance of 10 MΩ is often sufficient for a digital meter under normal conditions to eliminate significant errors from voltage drops, but a much higher requirement may be necessary for conditions with significant contact or other measurement circuit resistances such as dry sand, rock, gravel, frozen ground, paved surfaces, etc. One means of making accurate measurements is to use a potentiometer circuit in an analog meter.

4.3.1.2 The accuracy of potential measurements can be verified by using an instrument having two or more input impedances (internal resistance, for analog instruments) and comparing potential values measured using different input impedances. If the measured values are virtually the same, the accuracy is acceptable. Corrections need to be made if measured values are not virtually identical. Digital voltmeters that have a constant input impedance do not indicate a measurement error by changing voltage ranges. An alternative is to use a meter with a potentiometer circuit.

4.3.1.3 A voltmeter measures the potential across its terminals within its design accuracy. However, current flowing through the instrument creates measurement errors caused by voltage drops that occur in all resistive components of a measurement circuit.

4.3.2 Analog-to-digital converters used in digital and data logging instruments might sample only a portion of the input wave form and provide incorrect voltage values.

4.3.3 Parallax errors on an analog instrument can be minimized by viewing the needle perpendicular to the face of the instrument on the centerline projected from the needle point or by aligning the needle with its mirror image if the scale is equipped with a mirror.

4.4 Instrument Accuracy

4.4.1 The voltmeters are to be calibrated at least annually to confirm that it meets the manufacturer's specified accuracy. If an instrument is insufficiently accurate, the instrument shall be replaced with a calibrated voltmeter.

Section 5: Structure-to-Electrolyte Potential Measurements

5.1 Instruments used to measure AC voltage, DC voltage, or other electrical functions usually have one terminal designated "Common" (COM). The terminal either is black in color or has a negative (-) symbol. The positive terminal either is red in color or has a positive (+) symbol. The positive and negative symbols in the meter display indicate the current flow direction through the instrument (Figure 1[a]). For example, a positive symbol in the meter display indicates current flowing from the positive terminal through the meter to the negative terminal. One instrument test lead is usually black in color and the other red. The black test lead is connected to the negative terminal of the instrument and the red lead to the positive terminal.

- 5.2** Voltage measurements should be made using the lowest practicable range on the instrument.
- 5.3** The usual technique to determine the DC voltage across battery terminals, structure metal/electrolyte interface, or other DC system is to connect the black test lead to the negative side of the circuit and the red test lead to the positive side of the circuit. When connected in this manner, an analog instrument needle moves in an upscale (clockwise) direction indicating a positive value with relation to the negative terminal. A digital instrument connected in the same manner displays a value, sometimes preceded by a positive (+) symbol or otherwise no polarity is indicated. In each situation, the measured voltage is positive with respect to the instrument's negative terminal. (See instrument connections in Figure 1[a].)

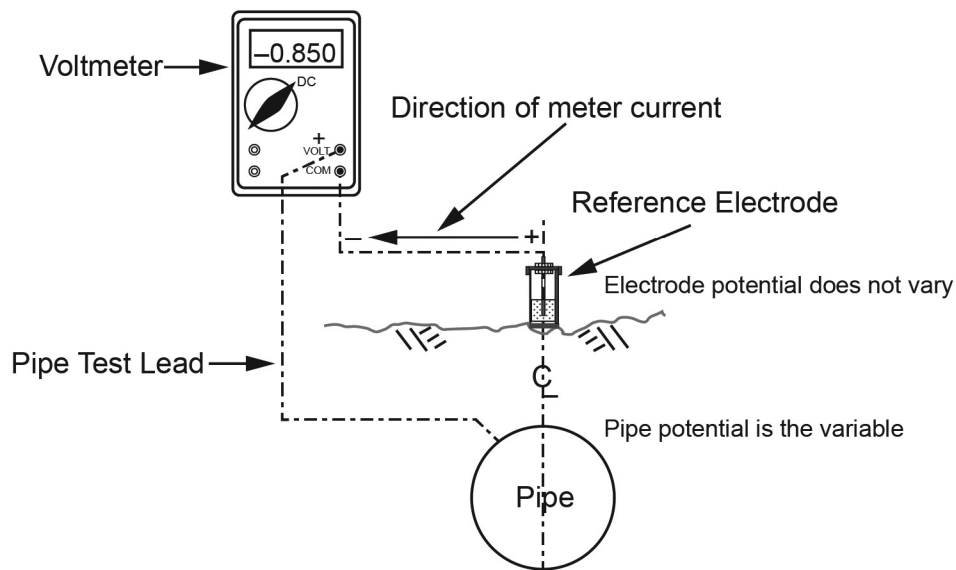


Figure 1(a): Instrument Connection (Polarity Option 1) Recommended

- 5.4** The voltage present between a reference electrode and a metal structure can be measured with a DC voltmeter. The reference electrode potential is normally positive with respect to a ferrous structure; conversely, the ferrous structure is negative with respect to the reference electrode.
- 5.5** A structure-to-electrolyte potential is measured using a DC voltmeter having an appropriate input impedance (or internal resistance, for an analog instrument), voltage range(s), test leads, and a stable reference electrode, such as a saturated copper/copper sulfate [(Cu/CuSO₄) CSE], silver/silver chloride [(Ag/AgCl) SSC], or saturated potassium chloride (KCl) or calomel reference electrode (SCE).
- 5.5.1** The CSE is usually used for measurements when the electrolyte is soil or fresh water and less often for salt water. When a CSE is used in a high-chloride environment, the stability (lack of contamination) of the CSE must be determined before the readings may be considered valid.
- 5.5.2** The SSC reference electrode is usually used in seawater environments.
- 5.5.3** The SCE is used more often for laboratory work. However, more rugged, polymer body, gel-filled SCEs are available, though modifications may be necessary to increase contact area with the environment.

5.5.4 See Appendix A (mandatory) for further information on reference electrodes.

5.6 Meter Polarity

5.6.1 Polarity Option 1

Structure-to-electrolyte potential measurements taken with a DC voltmeter are made with the reference electrode connected to the instrument negative terminal and the structure (e.g. pipeline) to the positive terminal. Figure 1(a) illustrates this connection for the example of a pipeline with a digital voltmeter.

5.6.2 Polarity Option 2

Structure-to-electrolyte potentials may be measured by connecting the instrument negative terminal to the structure and the positive terminal to the reference electrode, which is in contact with the structure electrolyte. With this connection, the instrument indicates that the reference electrode is positive with respect to the structure. Because the reference electrode has a positive value with respect to the structure, the structure voltage is negative with respect to the reference electrode (see Figure 1(b)).

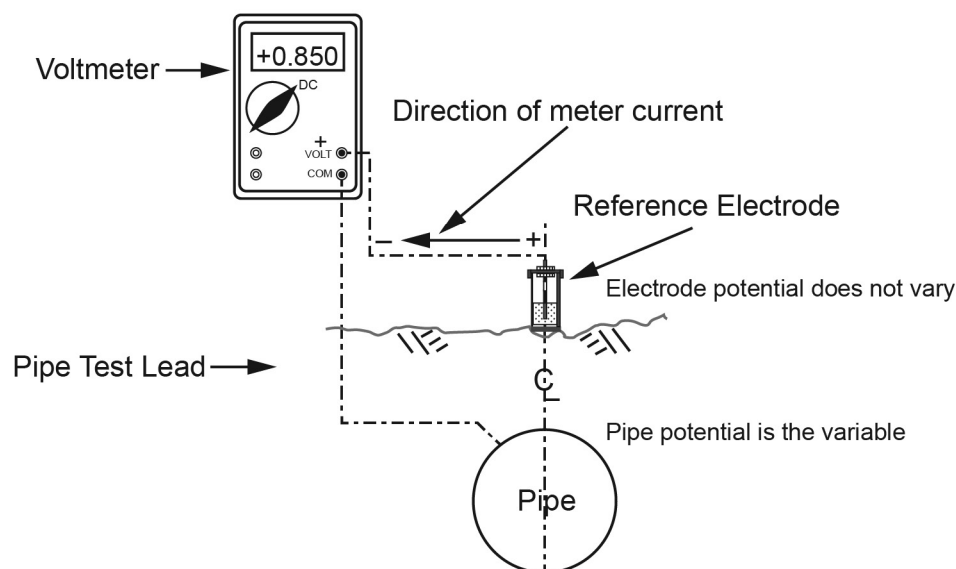


Figure 1(b): Instrument Connection (Polarity Option 2)

5.7 Accurate structure-to-electrolyte potential measurements of a buried structure are made with the reference electrode placed close to the metal/electrolyte interface of the structure. The common practice, however, is to place the reference electrode as close to the structure as practicable, which is usually at the surface of the earth above the centerline of the structure. (See Figure 1[a]). This measurement includes a combination of the voltage drops associated with the:

- (a) Voltmeter;
- (b) Test leads;
- (c) Reference electrode;
- (d) Electrolyte;
- (e) Coating, if applied;
- (f) Structure; and
- (g) Pipe metal/electrolyte interface.

5.8 The structure-to-electrolyte potential measurement as described above is a result of the:

- (a) Voltage drop created by current flowing through the electrical resistances of the items listed in Paragraph 5.7; and
- (b) For coated pipe, the influence of coating holidays, depending on their location, number, and size.

5.9 Structure-to-electrolyte potential measurements made to determine the level of cathodic protection at the test site should consider the following:

- (a) Effectiveness of coatings, particularly those known or suspected to be deteriorated or damaged;
- (b) Bare sections of structure;
- (c) Bonds to mitigate interference;
- (d) Parallel coated pipelines, electrically connected and polarized to different potentials;
- (e) Shielding;
- (f) Effects of other structures on the measurements;
- (g) History of corrosion leaks and repairs;
- (h) Location of impressed current anodes;
- (i) Unknown, inaccessible, or direct connected galvanic anodes;
- (j) Location of isolation devices, including high-resistance structure connections and compression couplings;
- (k) Presence of electrolytes, such as unusual corrosives, chemical spills, extreme soil resistivity changes, acidic waters, and contamination from sewer spills;
- (l) Location of shorted or isolated casings;
- (m) DC interference currents, such as HVDC, telluric, welding equipment, foreign rectifier, mining equipment, and electric railway or transit systems;
- (n) Contacts with other metals or structures;
- (o) Locations where the structure enters and leaves the electrolyte;
- (p) Areas of construction activity during the structure history;
- (q) Underground metallic structures close to or crossing the subject pipeline;
- (r) Valves and other appurtenances; and
- (s) HVAC power lines.

5.10 Voltage drops other than those across the structure-to-electrolyte interface shall be considered for valid interpretation of structure-to-electrolyte voltage measurements made to satisfy a criterion. Measurement errors must be minimized to ensure reliable structure-to-electrolyte potential measurements. Synchronous interruption or other valid methods can be used to evaluate the effect of voltage drops on the structure-to-electrolyte potential measurement. The methodology used for consideration of the voltage drops other than those across the structure-to-electrolyte interface, the environment conditions, the conditions of the structure, and the operating conditions of the cathodic protection system shall be documented for validation of the criterion for CP.

5.11 The effect of voltage drops on a structure-to-electrolyte potential measurement can be determined by interrupting all current sources that influence the potential and then making the measurement (for the use of cathodic protection coupons to address this issue, refer to Appendix C). This measurement is referred to as an instant-OFF potential. The measurement must be made without perceptible delay after current interruption to avoid loss of polarization. The voltage value measured is the polarized potential of the pipe at that location, if all voltage drops other than across the structure metal electrolyte interface have been eliminated. The current interruption may cause a voltage spike, recording the spike as the instant-OFF potential must be avoided. The magnitude and duration of the voltage spike can vary; however, the duration is typically within 0.3 second.¹⁷

5.11.1 Where outside current sources that may have a detrimental influence are suspected, they shall be assessed independently as follows.

5.11.1.1 Interrupt the CP source with the detrimental source on and measure the ON and instant-OFF potentials.

5.11.1.2 Interrupt the detrimental source with the CP source on and measure the ON and instant-OFF potentials.

5.11.1.3 Synchronously interrupt the CP source and the detrimental source and measure the ON and instant-OFF potentials.

5.11.1.4 With interrupters in the CP source and the detrimental source on different cycles such that each condition above will occur during the cycles, the ON and instant-OFF potentials can be measured with a datalogger during one test.

Cautionary Note: Conditions that may create stray currents shall be avoided when interrupting detrimental and or protective current sources. Such a condition may occur when interrupting a bond instead of the DC power source.

5.12 The following are examples of when it may not be practical to interrupt all protective current sources to make the instant-OFF potential measurement.

5.12.1 Galvanic Anodes

5.12.1.1 Galvanic anodes connected directly to the structure without benefit of aboveground test stations or connections. Interruption requires excavation of the connections.

5.12.2 Impressed Current Systems

5.12.2.1 Galvanic anodes directly connected to structure protected using an impressed current system;

5.12.2.2 Multiple impressed current sources;

5.12.2.3 Impressed current devices on foreign structure; and

5.12.2.4 Numerous cross bonds to parallel structures, such as pipelines.

5.12.3 Natural and manmade stray currents, such as:

- (a) Telluric currents;
- (b) Electrical mass transit;
- (c) Mining operations;
- (d) Welding operations;
- (e) High voltage transmission lines, etc.; and
- (f) Long-line currents.

5.13 When voltage drops have been evaluated at a test location and the structure-to-electrolyte potential found to be satisfactory, the ON structure-to-electrolyte potential value may be used for monitoring until significant environmental, structural, or cathodic protection system parameters change or there is a significant change in the ON potential.

5.13.1 Significant environmental, structural, or cathodic protection system parameter changes may include:

- (a) Replacement or addition of piping;
- (b) Addition, relocation, or deterioration of cathodic protection systems;
- (c) Failure of electrical isolating devices;
- (d) Effectiveness of coatings; and
- (e) Influence of foreign structures.

5.13.2 The significant variation of the environmental conditions, the conditions of the structure, and the operating conditions of the cathodic protection system shall be compared to the conditions that existed when the previous instant off were measured. The definition of “significant change” shall be defined by the user to consider this paragraph.

5.14 After a CP system is operating, time may be required for the structure to polarize. This should be considered when the potential is measured at a test site on a newly protected structure or after a cathodic protection device is reenergized.

Section 6: Causes of Inaccurate Measurements

6.1 Some factors that contribute to inaccurate potential measurements include:

6.1.1 Structure and instrument test leads

- (a) Broken or frayed wire strands (may not be visible inside the insulation);
- (b) Damaged or defective test lead insulation that allows the conductor to contact wet vegetation, the electrolyte, or other objects;
- (c) Loose, broken, or faulty structure or instrument connections; and
- (d) Dirty or corroded connection points.

6.1.2 Reference electrode - (also see Appendix A)

- (a) Contaminated reference electrode solution or rod, and solutions of insufficient quantity or saturation (only laboratory-grade chemicals and distilled water, if water is required, should be used in a reference electrode);
- (b) Reference electrode plug not sufficiently porous to provide a conductive contact to the electrolyte;
- (c) Porous plug contaminated by asphalt, oil, salt or other foreign materials;
- (d) High-resistance contact between reference electrode and high resistivity electrolytes, such as dry or frozen soil, rock, gravel, vegetation, or paving material;
- (e) Reference electrode placed in the potential gradient of an anode;
- (f) Reference electrode positioned in the potential gradient of a metallic structure other than the one with the potential being measured;
- (g) Shielding;
- (h) Defective stationary reference electrode;
- (i) Temperature correction not applied when required;
- (j) Photosensitive measurement error (in CSE with a clear-view window) as a result of light striking the electrode electrolyte solution (photovoltaic effect);
- (k) Improper placement of the reference electrode; and
- (l) Contact between the reference electrode terminal and the electrolyte.

6.1.3 Unknown or inadvertent isolation, such as tubing fittings, pipe compression fittings, bell and spigot joints that cause the pipe to be electrically discontinuous between the test connection and the reference electrode location.

6.1.4 Parallel path inadvertently established by test personnel contacting instrument terminals or metallic parts of the test lead circuit, such as test lead clips and reference electrodes, while a potential measurement is being made.

6.1.5 Defective or inappropriate instrument, incorrect voltage range selection, instrument not calibrated or zeroed, or a damp instrument sitting on wet earth.

6.1.6 Instrument or measurement methods that fail to avoid the effects of voltage spikes produced by current interruption.

6.1.7 Polarity of the measured value incorrectly observed.

6.1.8 Cathodic protection current-carrying conductor used, such as the negative lead of a rectifier or a lead wire from a galvanic anode, as a test lead for a structure potential measurement.

6.1.9 Interference

6.1.9.1 Electromagnetic interference or induction resulting from AC power lines or radio frequency transmitters inducing test lead or instrument errors. This condition is often indicated by a rapidly fluctuating pointer movement on an analog instrument or erratic displays on digital voltmeters. A DC voltmeter must have sufficient AC rejection capability, which can be determined by referring to the manufacturer's specification.

6.1.9.2 Telluric or stray DC currents flowing through the earth and piping (see Appendix D).

6.1.10 Cathodic protection current interrupter problems, such as interrupters out of synchronization, or failing to switch CP current on or off.

6.1.11 Depolarization caused by extended interruption.

6.1.12 Not interrupting all known influencing current sources (see Appendix F).

6.1.13 Change in the structure cathodic protection circuit such as disconnecting bonds.

6.2 Reference electrode contact resistance for different environmental conditions is reduced by:

6.2.1 Soil moisture—If the surface soil is so dry that the electrical contact of the reference electrode with the electrolyte is impaired, the soil around the electrode may be moistened with water until the contact is adequate, allowing sufficient time for the reference electrodes to make good contact; using pointed reference electrode plugs to penetrate the dry crust of the soil; digging down to soil with more moisture; and using plugs that are more porous or plugs with larger surface area.

6.2.2 Contact surface area—Contact resistance may be reduced by using a reference electrode with a larger contact surface area.

6.2.3 Frozen soil—Contact resistance may be reduced by removing the frozen soil to permit electrode contact with unfrozen soil.

6.3 Concrete or asphalt paved areas—All readings shall be taken with reference electrodes that are in contact with the electrolyte. Readings shall not be taken through concrete or asphalt. Soil contact may be established through at-grade openings or by drilling a small hole through the concrete or asphalt, or by contacting a seam of soil between concrete and asphalt.

Section 7: Voltage Drops Other Than Across the Structure Metal/Electrolyte Interface

7.1 Voltage drops included in structure-to-electrolyte potential measurements occur in the following:

7.1.1 Measurement Circuit—The voltage drop other than across the structure metal/electrolyte interface in the measurement circuit is the sum of the individual voltage drops caused by the current flow in the measurement circuit through individual resistances that include:

- (a) Instrument test lead and connection resistances;
- (b) Reference electrode internal resistance;
- (c) Reference electrode-to-electrolyte contact resistance;
- (d) Coating resistance;
- (e) Pipe metallic resistance;
- (f) Electrolyte resistance;
- (g) Analog meter internal resistance; and
- (h) Digital meter internal impedance.

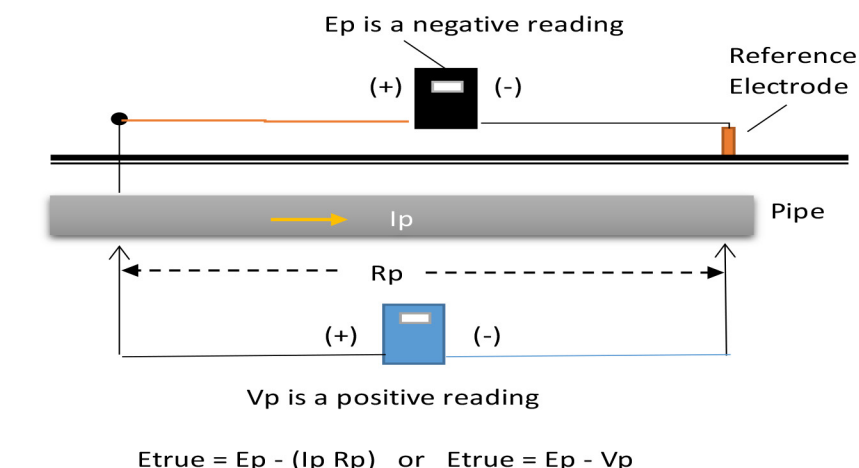
If the analog meter internal resistance or the digital meter internal impedance is not several orders of magnitude higher than the sum of the other resistances in the measurement circuit, then the magnitude of voltage drop errors in the measurement circuit becomes significant.

7.1.2 Structure—Current flowing within the structure (e.g., pipe wall) creates a voltage drop. This voltage drop and the direction of the current shall be considered when the reference electrode is not near the structure connection and significant current is conducted by the structure. Consideration is needed because an error in the structure-to-electrolyte potential measurement will occur if the structure current causes a significant voltage drop. Current away from the structure connection causes the measured potential to be less negative by the amount of the structure current voltage drop (see Figure 2[a] for the example of a pipeline). Conversely, the potential is more negative by that amount if the structure current direction is towards the structure connection (see Figure 2[b] for the example of a pipeline, also see NACE SP0207 for additional clarification).

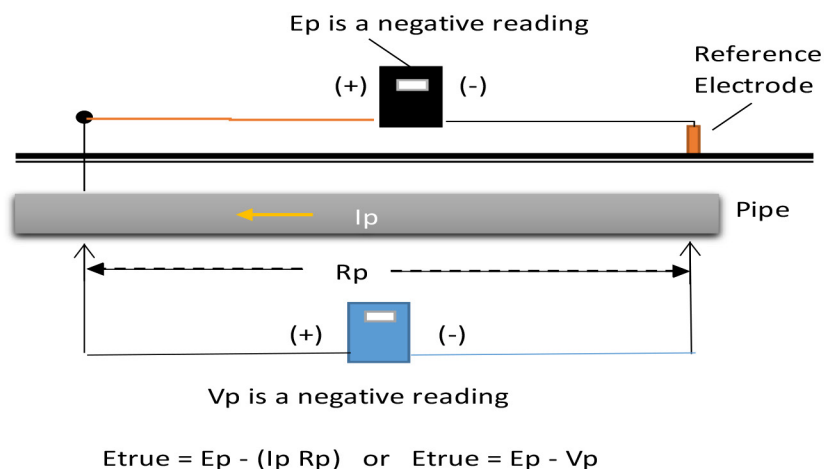
Measurement of the metallic voltage error (V_p) is typically made from one structure connection to the next. This voltage error is typically prorated based the distance to the reading divided by the total distance between the two connections but may be adjusted if the attenuation of potentials is not linear for that distance.

7.1.3 Electrolyte—When a structure-to-electrolyte potential is measured with cathodic protection current applied, the voltage drop in the electrolyte between the reference electrode and the metal/electrolyte interface shall be considered. Measurements taken close to sacrificial or impressed current anodes can contain a large voltage drop. Such a voltage drop can consist of, but is not limited to, the following:

A: Pipe Current Away from Pipe Connection



B: Pipe Current Towards Pipe Connection



E_p - measured structure-to-electrolyte potential (Volts)

I_p - Current in pipe (amperes)

R_p - Resistance of pipe between V_p contact points (Ohms)

Figure 2(a) and (b): Structure-to-Electrolyte Potential Correction due to Pipe Current

- (a) A voltage drop caused by current flowing to coating holidays when the structure is coated; and
- (b) A voltage drop caused by large voltage gradients in the electrolyte that occur near operating anodes.

7.1.3.1 Testing to locate galvanic anodes by moving the reference electrode along the centerline of the structure (pipe) may be necessary when the locations are not known.

7.1.3.2 Lateral potential measurements or side drain potential measurements may be used to validate the effectiveness of interruption of influencing CP current.

7.1.4 Coatings—Most coatings provide protection to the structure by reducing the structure surface contact with the environment. Because of the characteristic ionic impermeability of specific coatings, they resist current flow. While the electrical insulating ability of coatings reduces the current required for cathodic protection, coatings are not impervious to current flowing through them. Current flow through the coating causes a voltage drop that is greater than when the structure is bare, under the same environmental conditions.

Section 8: Test Method 1—Structure-to-Electrolyte Potential of Metallic Piping with Cathodic Protection Applied

8.1 Test Method 1 describes a procedure for measuring the structure-to-electrolyte potential of metallic piping with cathodic protection applied that is used to assess the adequacy of cathodic protection according to the criterion in NACE SP0169.3

8.2 General

8.2.1 Cathodic protection current shall remain on during the measurement process. This potential is commonly referred to as the ON potential.

8.2.2 Test Method 1 measures the structure-to-electrolyte potential as the sum of the polarized potential and any voltage drops in the circuit. These voltage drops include those through the electrolyte and pipeline coating from current sources such as impressed current, galvanic anodes, and telluric effects.

8.2.3 Because voltage drops other than those across the pipe metal/electrolyte interface may be included in this measurement, these drops shall be considered, as discussed in Paragraph 8.6.

8.2.4 Current sources that can affect the accuracy of this test method include the following:

- (a) Unknown, inaccessible, or direct connected galvanic anodes;
- (b) Cathodic protection systems on associated piping or foreign structures;
- (c) Electric railway systems;
- (d) HVDC and HVAC electric power systems;
- (e) Telluric currents;
- (f) Galvanic or bimetallic cells;
- (g) DC mining equipment;
- (h) Parallel coated structure, electrically connected and polarized to different potentials;
- (i) Uninterrupted current sources;
- (j) Unintentional connections to other structures or bonds to mitigate interference; and
- (k) Long-line currents.

8.3 Comparison with Other Methods

8.3.1 Advantages

- (a) Minimal equipment, personnel, and vehicles are required; and
- (b) Less time is required to make measurements.
- (c) Consistency in measurement techniques across technicians and geographic area.

8.3.2 Disadvantages

- (a) Potential measured includes voltage drops other than those across the pipe metal/electrolyte interface; and
- (b) Meeting the requirements for considering the significance of voltage drops (see Paragraph 8.6) can result in added time to assess adequacy of cathodic protection at the test site.

8.4 Basic Test Equipment

8.4.1 Voltmeter with adequate input impedance.

8.4.2 Two color-coded meter leads with clips for connection to the pipeline and reference electrode.

8.4.3 Reference electrode, e.g., CSE or other standard reference electrode: These reference electrodes are described in Appendix A, Paragraph A2.

8.5 Procedure

8.5.1 Before and during the test, appropriate safety measures shall be taken. See Section 3 Safety Considerations for guidance.

8.5.2 Before the test, verify that cathodic protection equipment has been installed and is operating properly. Sufficient time should be allowed to pass for the pipeline potentials to reach polarized values.

8.5.3 Determine the locations of the sites to be tested. Selection of a site may be based on:

- (a) Location accessible for future monitoring;
- (b) Other protection systems, structures, and anodes that may influence the structure-to-electrolyte potential;
- (c) Electrical midpoints between protective devices;
- (d) Known location of an ineffective coating if the line is coated; and
- (e) Location of a known or suspected corrosive environment.

8.5.4 Make electrical contact between the reference electrode and the electrolyte at the test site, directly over the centerline of the pipeline or as close to it as is practicable.

8.5.5 Connect the voltmeter to the pipeline and reference electrode as described in Paragraph 5.6.

8.5.6 Record the structure-to-electrolyte potential and its polarity with respect to the reference electrode.

8.6 Consideration of the Significance of Voltage Drops for Valid Interpretation of the Potential Measured

Consideration is understood to mean the application of sound engineering practice by one or more of the following:

8.6.1 Measuring or calculating the voltage drop(s) to establish whether a potential of negative 850 mV or more negative across the structure-to-electrolyte boundary has been achieved.

8.6.2 Use of coupons to establish levels of current density, free corrosion, levels of polarization, corrosion rates, and comparisons between coupon and pipe potentials.

8.6.3 Performing a technical evaluation of the system that confirms sufficient polarization has been achieved to control corrosion including data or information such as the following, used either separately or in combination, which the user deems necessary and sufficient for the situation:

8.6.3.1 Reviewing the historical performance of the CP system, such as type of CP, consistency with time of the potentials at individual test points along the line, consistency of CP current over time, number of years with CP, remedial CP activities, consistency of CIPS over time, and external corrosion-related leak history. (Note: Leak history should not be used as the sole means of determining adequate levels of CP). When reviewing the historical performance of the CP system, physical characteristics and results of direct examinations and the environment should also be considered.

8.6.3.2 Determining whether there is evidence of corrosion, such as by direct examination to determine evidence of active corrosion and correlation of direct examination data with other data such as CIPS, DCVG surveys, and ILI results. When direct examinations are used, the number and extent of the examinations performed as well as a comparison of the environments and their relevance should be considered. Corrosion should be investigated by root cause analysis per NACE SP0502 ECDA.

8.6.3.3 Evaluating the physical and electrical characteristics of the pipe and its environment, such as type of electrolyte, electrolyte resistivity, pH, dissolved oxygen content, moisture content, degree of aeration, differences in pipe metallurgy and installation dates, and variations in coating types and condition.

8.6.3.4 Physical characteristics and operational data, such as coated or bare, type of coating and possibility to shield CP, proximity to other lines, especially other lines in the right-of-way, temperature of the pipe, depth of the pipe, proximity to potential stray current sources such as light rail systems, HVAC and HVDC systems, foreign structures with CP, proximity and electrical isolation with structures of varying metals where mixed-metal potentials are a concern, locations where concrete weights and anchors are installed, and changes in operating conditions over time. Construction-related information alone might not provide sufficient information to adequately evaluate the effectiveness of CP, but should be considered during direct examinations and reviewing historical performances.

8.6.3.5 Evaluation of indirect inspection data, such as above-grade electrical surveys, ILI, and direct assessment.

Section 9: Test Method 2—Polarized Structure-to-Electrolyte Potential of Metallic Piping

9.1 Test Method 2 describes a procedure for measuring the polarized structure-to-electrolyte potential of metallic piping that is used to assess the adequacy of cathodic protection according to the criterion stated in NACE SP0169.³ This method uses current interruption to eliminate the cathodic protection system voltage drop from the structure-to-electrolyte potential measurement.

9.2 General

9.2.1 Interrupting the cathodic protection current source(s) eliminates voltage drops associated with the influencing currents being interrupted. However, significant voltage drops may also occur because of currents from non-interrupted sources, as discussed in Section 7.

9.2.2 To avoid significant depolarization of the pipe, the off period should be limited to the time necessary to make an accurate potential measurement. The off period is typically less than 3 seconds, however longer off periods may be required for systems including PCR's (Polarization Cell Replacement) or other decoupling equipment.

9.2.3 The magnitude and duration of a voltage spike caused by current interruption can vary, but the duration is typically within 0.3 second.¹⁷ After the current is interrupted, the time elapsed until the measurement is recorded should be long enough to avoid errors caused by voltage spiking. On-site measurements with appropriate instruments may be necessary to determine the duration and magnitude of the spiking.

9.2.4 Current sources that can affect the accuracy of this test method include the following:

- (a) Impressed current or galvanic anodes;
- (b) Cathodic protection systems on associated piping or foreign structures;
- (c) Electric railway systems;
- (d) HVDC and HVAC electric power systems;
- (e) Telluric currents;
- (f) Galvanic or bimetallic cells;
- (g) DC mining equipment;
- (h) Parallel pipelines, electrically connected and polarized to different potentials;
- (i) Uninterrupted current sources;
- (j) Unintentional connections to other structures or bonds to mitigate interference; and
- (k) Long-line currents.

9.2.5 Physical evidence of absence of external metal loss (ILI, direct examination, leaks due to external metal loss) and the guidelines presented in Paragraph 8.6.3 shall be considered to validate the CP criterion.

9.3 Comparison with Other Methods

9.3.1 Advantages

- (a) Voltage drops associated with the protective currents being interrupted are eliminated.

9.3.2 Disadvantages

- (a) Additional equipment is required;
- (b) Additional time, personnel, and vehicles may be required to set up equipment and to make structure-to-electrolyte potential measurements; and
- (c) Some depolarization may occur during the testing, demonstrating a lower level of protection than existed prior to the testing, especially if the instant-OFF period is greater than 1 to 2 seconds.
- (d) Test results are difficult or impossible to analyze when all influencing currents are not interrupted, such as stray currents, directly connected galvanic anodes, or foreign impressed current devices.
- (e) Difficult to trend/compare data due to complexity and multiple variables

9.4 Basic Test Equipment

9.4.1 Voltmeter with adequate input impedance.

9.4.2 Two color-coded meter leads with clips for connection to the pipeline and reference electrode.

9.4.3 Sufficient current interrupters are required for all influencing cathodic protection current sources. Also, special interrupters might be required to interrupt current sources such as high output single-phase rectifiers, three-phase rectifiers, constant-current or constant-potential controlled rectifiers, galvanic anodes, solar-power, thermoelectric generators, wind-powered generators, and micro-turbine and engine-generators.

9.4.4 Reference electrode, e.g., CSE or SSC reference electrode. These reference electrodes are described in Appendix A, Paragraph A2.

9.5 Procedure

9.5.1 Before and during the test, appropriate safety measures shall be taken. See Section 3 Safety Considerations for guidance.

9.5.2 Before the test, verify that cathodic protection equipment has been installed and is operating properly. Sufficient time should be allowed for the pipeline potentials to reach polarized values.

9.5.3 Install and place in operation necessary interrupter equipment in all influencing DC sources protecting the pipe at the test site, with a synchronized off and on cycle. The off portion of the cycle should be kept as short as possible but still long enough to read a polarized structure-to-electrolyte potential after any spike (as shown in Figure 3) has collapsed.

9.5.4 Determine the locations of the sites to be tested. Selection of a site may be based on:

- (a) Location accessible for future monitoring;
- (b) Other protection systems, structures, and anodes that may influence the structure-to-electrolyte potential;
- (c) Electrical midpoints between protection devices;
- (d) Known location of an ineffective coating when the pipeline is coated; and
- (e) Location of a known or suspected corrosive environment.

9.5.5 Make electrical contact between the reference electrode and the electrolyte at the test site, directly over the centerline of the pipeline or as close to it as is practicable.

9.5.6 Connect voltmeter to the pipeline and reference electrode as described in Paragraph 5.6.

9.5.6.1 If spiking may be present, use an appropriate instrument, such as an oscilloscope or high-speed recording device, to verify that the measured values are not influenced by a voltage spike.

9.5.7 Record the structure-to-electrolyte ON and OFF potentials and their polarities with respect to the reference electrode.

9.6 Synchronized interruption of multiple current sources is required for valid readings. The effective operation of all interrupters during the testing period should be confirmed (refer to SP0207).⁶ Additional testing to confirm effectiveness of voltage drop minimization is discussed in SP0207.⁶

Section 10: Test Method 3—Cathodic Polarization of Metallic Piping

10.1 Test Method 3 describes the use of either pipeline polarization decay or pipeline polarization formation to determine whether cathodic protection is adequate at the test site according to the criterion in NACE SP0169.³ Consequently, this test method consists of two mutually independent parts, Test Methods 3a and 3b, which describe the procedures for testing. Cathodic polarization time curves for Test Methods 3a and 3b are shown in Figures 3 and 4. These are schematic drawings of generic polarization decay and formation. Physical evidence of absence of external metal loss (ILI, direct examination, leaks due to external metal loss) and the guidelines presented in Paragraph 8.6.3 shall be considered to validate the CP criterion.

10.2 Other current sources that can affect the accuracy of this test method include the following:

- (a) Impressed current or galvanic anodes;
- (b) Cathodic protection systems on associated piping or foreign structures;
- (c) Electric railway systems;
- (d) HVDC and HVAC electric power systems;
- (e) Telluric currents;
- (f) Galvanic or bimetallic cells;
- (g) DC mining equipment;
- (h) Parallel structure, electrically connected and polarized to different potentials;
- (i) Uninterrupted current sources;
- (j) Bonds or unintentional connections to other structures; and
- (k) Long-line currents.

10.3 Test Method 3a—Pipeline Polarization Decay

10.3.1 Test Method 3a uses pipeline polarization decay to assess the adequacy of cathodic protection on metallic pipelines, in accordance with the criterion stated in NACE SP0169.³

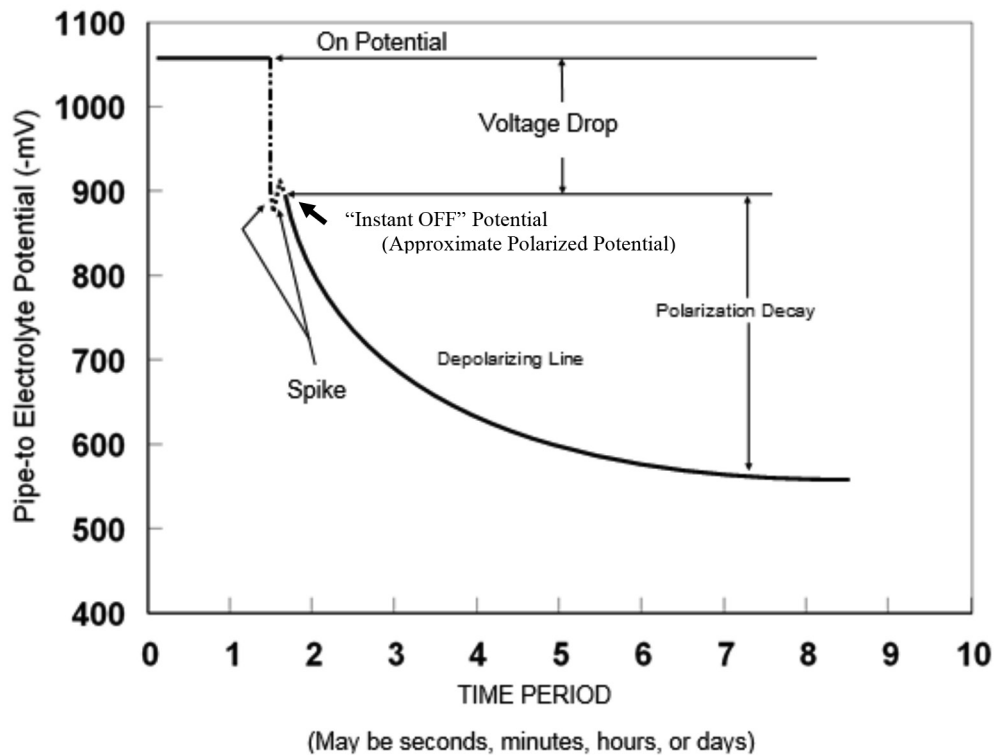


Figure 3: Polarization Decay

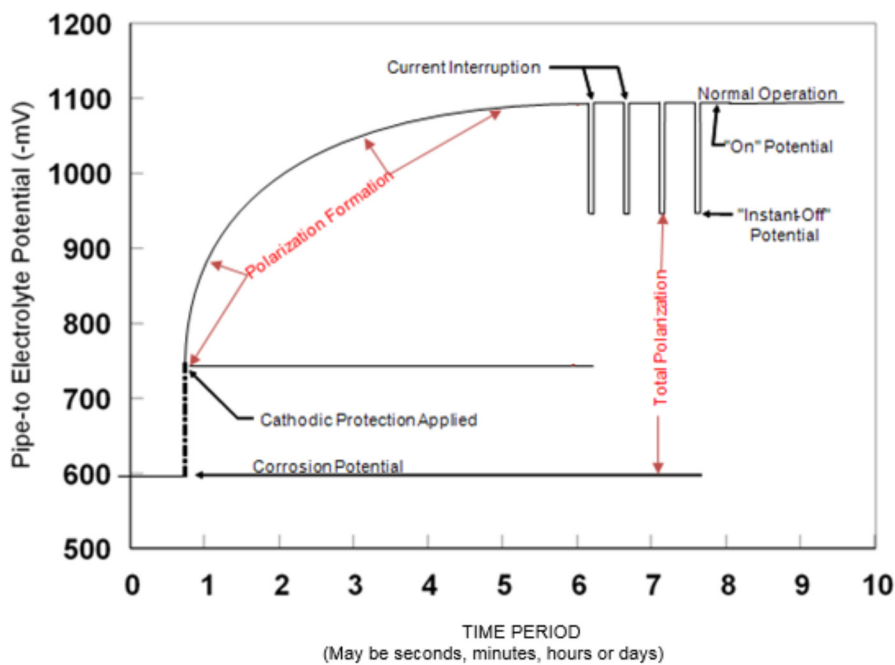


Figure 4: Polarization Formation

10.3.2 General

10.3.2.1 Interrupting the cathodic protection source(s) eliminates voltage drops associated with the influencing current(s) being interrupted. Voltage drops caused by uninterrupted sources will not be eliminated.

10.3.2.2 The magnitude and duration of a voltage spike caused by current interruption can vary, but the duration is typically within 0.3 second.¹⁷ After the current is interrupted, the time elapsed until the measurement is recorded should be long enough to avoid errors caused by voltage spiking. On-site measurements with appropriate instruments may be necessary to determine the duration and magnitude of the spiking.

10.3.2.3 If the pipe is depolarized for an excessive period, the pipe may be exposed to galvanic and stray current corrosion. Additionally, the pipe may require an extended period for the previous level of polarization to be regained.

10.3.3 Comparison with Other Methods

10.3.3.1 Advantages

- (a) This method is especially useful for bare or ineffectively coated structure; and
- (b) This method is advantageous when corrosion potentials may be low or the current required to meet a polarized potential criterion would be considered excessive.

10.3.3.2 Disadvantages

- (a) Additional equipment is required;
- (b) Additional time, personnel, and vehicles may be required to set up equipment and to make structure-to-electrolyte potential measurements; and
- (c) Test results are difficult or impossible to analyze when all influencing currents are not interrupted, such as stray currents, directly connected galvanic anodes, or foreign impressed current devices.

10.3.4 Basic Test Equipment

10.3.4.1 Voltmeter with adequate input impedance.

10.3.4.1.1 Recording voltmeters can be useful to record polarization decay.

10.3.4.2 Two color-coded meter leads with clips for connection to the pipeline and reference electrode.

10.3.4.3 Sufficient current interrupters are required for all influencing cathodic protection current sources. Also, special interrupters might be required to interrupt current sources such as high-output single-phase rectifiers, three-phase rectifiers, constant-current or constant-potential controlled rectifiers, galvanic anodes, solar power, thermoelectric generators, wind power, and micro-turbine and engine-generator.

10.3.4.4 Reference electrode

10.3.4.4.1 CSE.

10.3.4.4.2 Other standard reference electrodes may be substituted for the CSE. These reference electrodes are described in Appendix A, Paragraph A2.

10.3.5 Procedure

10.3.5.1 Before and during the test, appropriate safety measures shall be taken. See Section 3 Safety Considerations for guidance.

10.3.5.2 Before the test, verify that cathodic protection equipment has been installed and is operating properly. Time is to be allowed for the pipeline potentials to reach polarized values.

10.3.5.3 Install and place in operation necessary interrupter equipment in all influencing DC sources protecting the pipe at the test site, with a synchronized off and on cycle. The off portion of the cycle should be kept as short as possible but still long enough to read a polarized structure-to-electrolyte potential after any spike (as shown in Figure 3) has collapsed.

10.3.5.4 Determine the locations of the sites to be tested. Selection of a site may be based on:

- (a) Location accessible for future monitoring;
- (b) Other protection systems, structures, and anodes that may influence the structure-to-electrolyte potential;
- (c) Electrical midpoints between protection devices;
- (d) Known location of an ineffective coating if the pipeline is coated; and
- (e) Location of a known or suspected corrosive environment.

10.3.5.5 Make electrical contact between the reference electrode and the electrolyte at the test site, directly over the centerline of the pipeline or as close to it as is practicable.

10.3.5.5.1 Identify the location of the reference electrode when measuring the instant-OFF potential so that the depolarized potential can be measured at the same location.

10.3.5.6 Connect the voltmeter to the pipeline and reference electrode as described in Paragraph 5.6.

10.3.5.7 If spiking may be present, use an appropriate instrument, such as an oscilloscope or high-speed recording device, to verify that the measured values are not influenced by a voltage spike. This equipment may also be used to verify proper synchronization of interruption.

10.3.5.8 Measure and record the synchronized structure-to-electrolyte ON and instant-OFF potentials and their polarities with respect to the reference electrode.

10.3.5.8.1 The synchronized instant-OFF structure-to-electrolyte potential is the baseline potential from which the polarization decay is calculated.

10.3.5.9 Turn off sufficient cathodic protection current sources that influence the pipe at the test site until the desired cathodic polarization decay has been attained or a stable depolarized level has been reached.

10.3.5.9.1 Measurements shall be made at sufficiently frequent intervals to avoid having the CP current off for an unnecessarily extended period.

10.3.5.9.2 When extended polarization decay time periods are anticipated, it may be desirable to use recording voltmeters to determine when adequate polarization decay or a corrosion potential has been attained.

10.3.5.9.3 Note that if only a subset of the CP power sources is turned off, the resulting calculation between the polarized and depolarized potential may indicate an unrealistically low level of cathodic polarization causing remedial activity that may subsequently result in excessive high levels of polarization.

10.4 Test Method 3b—Pipeline Polarization Formation

10.4.1 Test Method 3b uses pipeline polarization formation (see Figure 4) to assess the adequacy of cathodic protection at a test site on piping according to the criteria stated in NACE SP0169.³

10.4.2 General: Metallic pipelines may be adequately cathodically protected if applying cathodic protection causes the desired polarization change with respect to a reference potential.

10.4.3 Comparison with Other Methods

10.4.3.1 Advantages

- (a) This method is especially useful for bare or ineffectively coated pipe; and
- (b) This method is advantageous when corrosion potentials may be low or the current required to meet a polarized potential criterion would be considered excessive.

10.4.3.2 Disadvantages

- (a) Additional equipment is required;
- (b) Additional time, personnel, and vehicles may be required to set up the equipment and to make structure-to-electrolyte potential measurements.

10.4.4 Basic Test Equipment

10.4.4.1 Voltmeter with adequate input impedance.

10.4.4.2 Two color-coded meter leads with clips for connection to the pipeline and reference electrode.

10.4.4.3 Sufficient current interrupters are required for all influencing cathodic protection current sources. Also, special interrupters might be required to interrupt current sources such as high-output single-phase rectifiers, three-phase rectifiers, constant-current or constant-potential controlled rectifiers, galvanic anodes, solar-power, thermoelectric generators, wind-power generators, and micro-turbine and engine-generators.

10.4.4.4 Reference electrode, CSE, or other standard reference electrode. These reference electrodes are described in Appendix A, Paragraph A2.

10.4.5 Procedure

10.4.5.1 Before and during the test, appropriate safety measures shall be taken. See Section 3 Safety Considerations for guidance.

10.4.5.2 Before the test, verify that cathodic protection equipment has been installed but is not energized.

10.4.5.3 Determine the locations of the sites to be tested. Selection of a site may be based on:

- (a) Location accessible for future monitoring;
- (b) Other protection systems, structures, and anodes that may influence the structure-to-electrolyte potential;
- (c) Electrical midpoints between protection devices;
- (d) Known location of an ineffective coating if the structure is coated; and
- (e) Location of a known or suspected corrosive environment.

10.4.5.4 Make electrical contact between the reference electrode and the electrolyte at the test site, directly over the centerline of the pipeline or as close to it as is practicable.

10.4.5.4.1 Identify the reference electrode location when measuring the potential so that the subsequent potentials can be measured at the same reference electrode location.

10.4.5.5 Connect the voltmeter to the pipeline and reference electrode as described in Paragraph 5.6.

10.4.5.6 Measure and record the structure-to-electrolyte corrosion potential and its polarity with respect to the reference electrode.

10.4.5.6.1 This potential is the value from which the polarization formation is calculated.

10.4.5.7 Apply the cathodic protection current. Time should be allowed for the pipeline potentials to reach polarized values.

10.4.5.7.1 When extended polarization gain time periods are anticipated, it may be desirable to use recording voltmeters to determine when adequate polarization gain or a protective potential has been attained.

10.4.5.8 Install and place in operation necessary interrupter equipment in all influencing DC sources protecting the pipe at the test site, with a synchronized off and on cycle. The off portion of the cycle should be kept as short as possible but still long enough to read a polarized structure-to-electrolyte potential after any spike (as shown in Figure 4) has collapsed.

10.4.5.9 Measure and record the structure-to-electrolyte ON and OFF potentials and their polarities with respect to the reference electrode. The difference between the OFF potential and the corrosion potential is the amount of polarization formation.

10.4.5.9.1 If spiking may be present, use an appropriate instrument, such as an oscilloscope or high-speed recording device, to verify that the measured values are not influenced by a voltage spike.

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⁽³⁾ ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

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Appendix A: Reference Electrodes (Mandatory)

- A1** Pipeline metals have unstable electrical potentials when placed in an electrolyte such as soil or water. However, a half-cell that has a stable, electrochemically reversible potential characterized by a single, identifiable half-cell reaction is a reference electrode. The stability of a reference electrode makes it useful as an electrical reference point or benchmark for measuring the potential of another metal in soil or water. When connected by a voltmeter to another metal in soil or water, the reference electrode becomes one half of a corrosion cell. The reference electrodes used for measuring potentials on buried or submerged pipelines have voltage values that are normally positive with respect to steel.
- A2** Pipeline potentials are usually measured using either a saturated copper/copper sulfate (CSE), a silver/silver chloride SSC, or a saturated potassium chloride (KCl) calomel reference electrode (SCE). CSEs are usually used for measurements when the electrolyte is soil or fresh water, and less often for salt water. When a CSE is used in a high-chloride environment, the stability (i.e., lack of contamination) of the electrode must be determined before the readings may be considered valid. SSC reference electrodes are usually used for seawater environments. The SCE reference electrodes are more often used for laboratory work because they are generally less rugged, unless specially constructed, than the other two reference electrodes.

⁽⁴⁾ American Gas Association (AGA), 400 N. Capitol St. NW, Suite 450, Washington, DC 20001.

Table A1
Common Reference Electrodes and Their Potentials and Temperature Coefficients

Reference Electrode	Electrolyte Solution	Potential at 25 °C [77 °F] (V/SHE)	Potential at 25 °C [77 °F] (V/CSE)	Temperature Coefficient mV/°C (mV/°F)	Typical Usage
Cu/CuSO ₄ (CSE)	Sat. CuSO ₄	+0.316 ⁸	0	0.9 ⁸ (0.5)	Soils, fresh water
Ag/AgCl ^(A) (SSC)	0.6 M NaCl (3 ½%)	+0.256 ¹³	−0.06	−0.33 ¹³ (0.18)	Seawater, brackish ^(B)
Ag/AgCl ^(C) (SSC)	Sat. KCl	+0.222 ¹⁴	−0.094	−0.70 ¹⁴ (0.39)	Brackish soils, water
Sat. Calomel (SCE)	Sat. KCl	+0.244 ²	−0.072	−0.70 ² (0.39)	Water, laboratory
Zn (ZRE)	Saline solution	−0.79 ± 0.1 ¹¹	1.1 ± 0.1 ¹¹	—	Seawater
Zn (ZRE)	Soil	−0.80 ± 0.1 ¹¹	1.1 ± 0.1 ¹¹	—	Underground

^(A) Solid junction.

^(B) Potential becomes more electropositive with increasing resistivity. See nomograph for correction in waters of varying resistivity in NACE SP0176,² or see reference 13.

^(C) Liquid junction.

A2.1 The voltage equivalents (at 25 °C [77 °F]) to negative 850 mV referred to a CSE are:

A2.1.1 SSC seawater reference electrode (without controlled electrolyte) used in 25 ohm-cm seawater: −800 mV,⁸

A2.1.2 Saturated SCE reference electrode: −780 mV, and

A2.1.3 SSC reference electrode used in saturated KCl electrolyte: approximately −740 mV.

NOTE: SP0169-2013³ does not require temperature correction within 10 °C [18 °F] of 25 °C [77 °F]. However, if the reference electrode is at a temperature where the error could affect whether the criterion is met, then the temperature correction should be applied (see Table A1 for correction factors).

Examples: −850 mV CSE measured at 37.8 °C (100 °F) would be corrected to −838.5 mV at 25 °C (77 °F) (the actual potential is 11.5 mV less negative than the reading), while −850 mV measured at 4.4 °C (40 °F) would be corrected to −868.5 mV at 25 °C (77 °F) (18.5 mV more negative than the reading). (1 mV/°C = 0.55 mV/°F)

A2.2 A CSE is composed of a pure copper rod immersed in a saturated solution of distilled water and copper sulfate (CuSO₄). The pure copper rod extends from one end of the reference electrode, providing a means of connection to a voltmeter. The other end of the reference electrode has a porous plug that is used to make an electrical contact with the pipeline electrolyte. Unless a gel-type reference electrode, dissolved CuSO₄ crystals in the reference electrode should be visible or heard when shaken to ensure the solution is saturated. The reference is reasonably accurate (within 5 mV when measured against a reference electrode known to be free of contamination). The advantages of this reference electrode are low cost and ruggedness.

A2.3 SSC reference electrodes are used in marine and soil environments. The construction and the electrode potential vary with the application and with relation to the potential of a CSE reference electrode. The electrolytes involved may be natural seawater, saturated KCl, or other concentrations of KCl. The user shall utilize the manufacturer's recommendations and potential values for the type of SSC cell used. The SSC reference electrode has a high accuracy (typically less than 2 mV when handled and maintained correctly) and is very durable.

A2.4 An SCE reference electrode for laboratory use is composed of a platinum wire in contact with a mercury/mercurous chloride mixture contacting a saturated KCl solution enclosed in a glass container, a voltmeter connection on one end, and a porous plug on the other end for contact with the pipeline electrolyte. The presence of mercury in this electrode makes it environmentally less desirable for field use. For field use, a more rugged, polymer-body, gel-filled KCl calomel electrode is available, though modifications may be necessary to increase contact area with the environment.

A2.5 In addition to these standard reference electrodes, an alternative metallic material or structure may be used in place of the saturated CSE if the stability of its electrode potential is ensured and if its voltage equivalent referred to a CSE is established.

A2.6 Stationary reference electrodes may be used if their accuracy has been verified.

- A3** It is essential to routinely verify and record the accuracy of reference electrodes to be used in the field by comparing them with a carefully prepared master reference electrode that, to avoid contamination, is never used for field measurements. The accuracy of a field reference electrode can be verified by placing it along with the master reference electrode in a common solution as per TM0113 and measuring the voltage difference between the two electrodes.¹² A voltage difference between a master reference electrode and another reference electrode of the same type may be used for corrections to improve data accuracy. The potential difference between the electrodes shall be considered in deciding whether or not to correct field measurements or to replace/recondition the field electrode. A voltage difference within 5 mV between a master reference electrode and another reference electrode of the same type is usually satisfactory for structure potential measurements. Where the structure-to-electrolyte potentials are within 5 mV of the criterion, the difference must be considered or the reference electrode shall be serviced.¹² TM0113-latest revision, "Evaluating the Accuracy of Field-Grade Reference Electrodes."

Appendix B: DC Cell-to-Cell Surface Potential Gradient Surveys (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.

B1 Introduction

B1.1 This section addresses DC cell-to-cell surface potential gradient surveys used to predict the direction of corrosion current or CP current in the soil. When using soil current measured by this technique, it must be noted that this test will not likely detect corrosion current in local corrosion cells and thus the prediction of corrosion or the effectiveness of cathodic protection is left to the interpreter's judgment. Cell-to-cell surveys (such as traditional DCVG or ACVG) used to evaluate the effectiveness of the coating are described in other NACE publications.^{6,16} These types of surveys are particularly suited for pipelines that are not electrically continuous or for pipelines that are bare or ineffectively coated. These techniques are not usually performed as stand-alone surveys on coated pipelines.

B1.2 There are two types of surface potential gradient surveys used to identify possible anodic areas on a pipeline:

- surveys measuring gradients along the pipeline, and
- surveys measuring gradients normal (perpendicular) to the pipeline (side drain).

Both techniques can be performed as a stand-alone survey or can be combined with CIPS as a hybrid survey (reference NACE SP0207).⁶ This section addresses stand-alone surface potential gradient surveys.

B1.3 A survey to identify anodic sections on a pipeline (hot-spots) is a cell-to-cell surface potential gradient survey measuring potential gradients along the pipeline, consisting of a series of potential differences along the pipeline measured between two matched electrodes (typically CSE) in contact with the earth.

B1.4 A side-drain survey is a cell-to-cell surface potential gradient survey measuring potential gradients normal (perpendicular) to the pipeline, consisting of a series of potential differences measured between two matched electrodes (typically CSE) in contact with the earth, one directly over the pipeline, and the other offset to either side of the pipeline. This type of survey can be used to locate suspected anodic conditions on the pipe and to evaluate a net current to or away from the pipeline to identify long-line corrosion activity.

B1.5 If the pipeline has a CP system, it should be noted that the potential measured may include current from other sources. To evaluate the current associated with the CP system, these surveys should be performed with CP current interrupted.

B2 Safety Considerations

B2.1 Safety considerations are similar to those listed in Section 3.

B3 Instrumentation and Equipment

B3.1 Instrumentation and equipment include a high impedance voltmeter and two matched reference electrodes. Surface potential gradient surveys do not require electrical connection to the pipeline.

B3.2 For these survey techniques to be effective, special attention must be given to the reference electrodes used. Because the surface potential gradient values to be measured can be expected to be much lower than for structure-to-electrolyte potentials, the reference electrodes must be within 2 mV. Electrical circuits or a calculated correction to adjust the potential difference between the reference electrodes to compensate for this difference may be used.

B3.3 The voltmeter shall have a sufficiently small scale (typically 100 mV full scale or smaller) to make accurate surface potential gradient measurements with an accuracy of ± 0.5 mV.

B3.4 The reference electrodes may be alternated (leap frogging), but data shall clearly indicate the polarity of the potentials and thus the direction of current by some convention and clearly identify polarity reversals.

B4 Minimizing Voltage Errors

B4.1 The potential measured is the voltage due to the current in the electrolyte however it must be recognized that current from other sources may exist in the electrolyte. Interrupting the intended CP current will define the current of interest.

B5 Pipe Location and Marking Procedures

B5.1 Accurate pipe location is critical for surface potential gradient surveys.

B6 Anodic (Hot-Spot) Survey Procedures

B6.1 The survey is performed by placing two reference electrodes in the earth, separated by the selected interval, directly over the center line of the pipe and measuring the potential difference. Careful placement of reference electrodes is essential when using the two-reference electrode surface survey. Minor measurement errors due to incorrect placement of the reference electrodes can result in misinterpretation of the data.

B6.2 Because the voltage values between the reference electrodes are normally low, each reference electrode contact with the earth must be of low resistance and be free of leaves, grass, rocks, and other debris. The reference electrodes shall be checked periodically for balance, and the operator should have matched or balanced spares available for replacement if needed. Alternately, a bias voltage can be applied (physically or mathematically), or the meter can be zeroed to balance the reference electrodes. Surveys in areas of dynamic stray currents are not recommended.

B6.3 Reference electrode spacing shall be uniform throughout the survey. Decreasing the interval provides better resolution and more precise location of anodic areas, but reduces the magnitude and therefore the accuracy of the potential measurements. An appropriate interval must be selected by balancing these factors. A spacing of 3 m (10 ft) is typical. When a ground gradient reversal (anodic condition) has been located, the spacing may be reduced (e.g., by one-half) and the area reexamined to locate the anodic area more closely. Further reference electrodes can be placed radially around the suspected anodic area to further define it.

B6.4 Data may be recorded on a form having a suitable format or recorded using a data logger. It may also be useful to provide a sketch of the area surveyed. Special attention must be given to ensure the polarity of each voltage measurement is recorded correctly.

B6.5 A common polarity convention is for the front reference electrode in the direction of travel to be connected to the positive terminal of the instrument (see Figure B1). The meter shall indicate the polarity of the measured potential and thus the direction of the current in the electrolyte.

B6.6 With the reference electrodes placed and the instrument connected as described, a possible anodic condition is indicated when a polarity change occurs. When the polarity of the measured value changes again, a possible cathodic condition is indicated. See Figure B1.

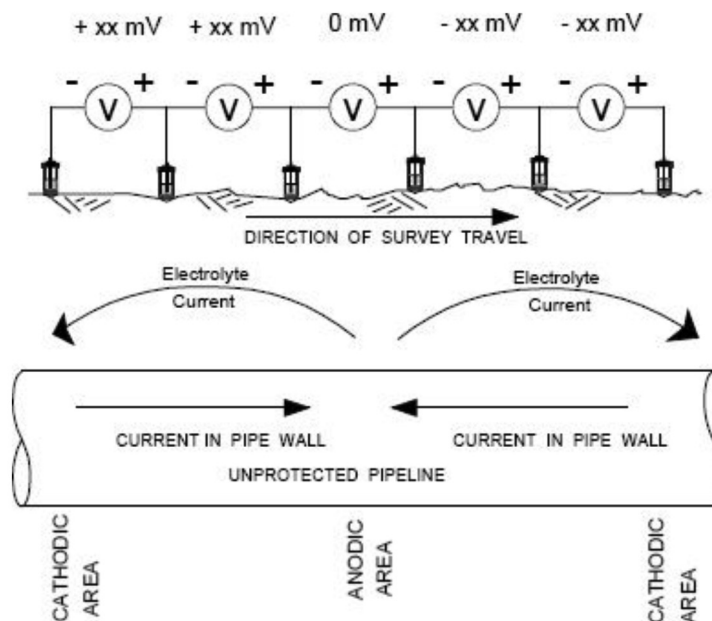


Figure B1: Hot-Spot Survey

NOTE: Actual readings are usually 50 mV or less. As the anodic condition in the center of the figure is passed (traveling left to right), the indicated polarity switches from positive to negative. This polarity reversal indicates a possible anodic condition. A switch from negative to positive indicates a current pickup or cathodic area.

B6.6.1 A suspected anodic condition is indicated by a change of the current away from a given point in both directions. The severity and extent of an anodic condition may be further determined by measuring side-drain potentials (Paragraph B.7). These tests are to be made on both sides of the pipe to verify that current is leaving the pipeline, and that the current is not leaving the structure via a galvanic anode. Sufficient measurements should be made along the pipe and to both sides of the pipe to define the limits of the anodic condition.

B6.6.2 The presence of a galvanic anode connected to the pipe affects surface potential gradient measurements and generally appears as an anodic condition along the pipeline however, if the anode is located away from the pipeline, this becomes apparent with side drain potentials. As a galvanic anode is approached, its presence is usually indicated by earth gradients that are somewhat higher than normal for the area being surveyed. The side-drain measurements may provide higher measured values on the side of the pipe on which the anode is buried and lower values on the side of the pipe opposite the anode. Service taps, side connections, other components of the pipe (such as mechanical couplings or screw collars with a higher metallic resistance than the pipe), or other close buried metallic structures may provide measured values that appear as an anodic condition. The side-drain measurements are useful to evaluate the initial data. Any situation not determined to be caused by some other factor is typically considered as an anodic condition.

B6.7 Adequate marking or precise survey coordinates (GPS) of anodic conditions are necessary so they can be located for future attention. Additional measurements such as structure-to-electrolyte potentials, soil resistivity, and pH measurements may be made at anodic indications. These tests may be helpful in predicting the severity of ongoing corrosion, anode current, and anode life.

B7 Side-Drain Survey Procedures

B7.1 The survey is performed by measuring surface potential gradients between two reference electrodes, one located directly over the pipeline and the other offset to each side of the pipeline, typically at a distance of approximately two and one-half times the pipe depth. Side-drain potentials may be measured on both sides of the pipeline to confirm that the current from another source is not “passing by.” Careful placement of reference electrodes is essential when performing surface potential gradient surveys. Minor measurement errors due to incorrect placement of the reference electrodes can result in misinterpretation of the data.

B7.2 In order to perform a continuous evaluation of the structure, the required survey interval depends on the depth of burial, and shall be less than three and a half times the depth of cover of the pipeline in order to obtain a continuous survey without gaps. Survey intervals shorter than the maximum may not provide more information, but may be used to ensure that occasional spurious data (scatter) do not result in a loss of information.

B7.3 Because the voltage values between the reference electrodes are normally low, the reference electrode contact with the earth shall be a low resistance and shall be free of leaves, grass, rocks, and other debris. The reference electrodes shall be checked periodically for balance, and the operator should have matched or balanced spares available for replacement if needed. Alternately, a bias voltage can be applied (physically or mathematically), or the meter can be zeroed to balance the reference electrodes. Surveys in areas of dynamic stray currents are not recommended unless a series of dataloggers are used.

B7.4 A common polarity convention is for the reference electrode offset from the pipeline to be connected to the positive terminal of the instrument (see Figure B2). Using this polarity convention, positive gradients indicate current toward the pipeline, and negative potential gradients indicate current away from the pipeline.

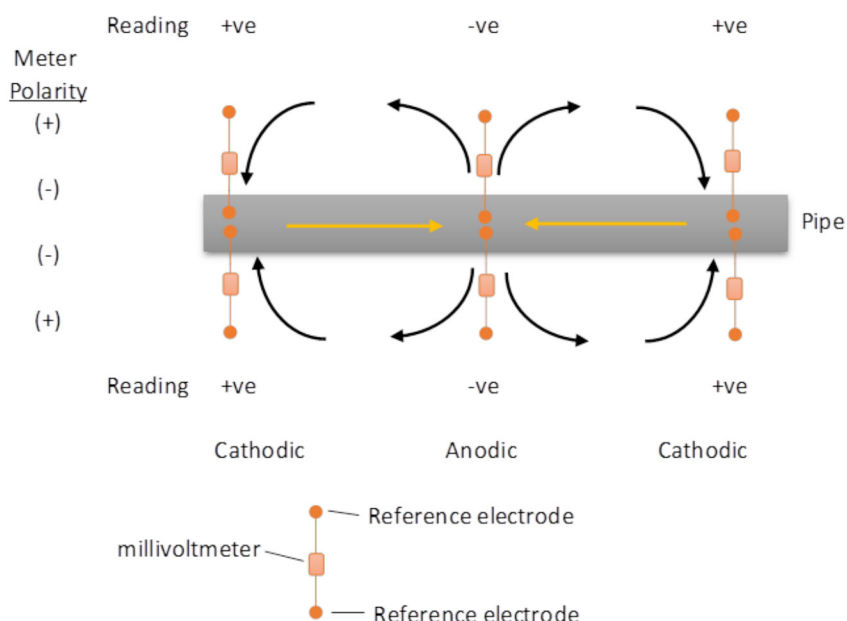


Figure B2: Side-Drain Survey

NOTE: Actual readings are usually 50 mV or less. As the anodic condition in the center of the figure is passed (traveling left to right), the polarity of the side-drain measurements switch from toward the pipe to away from the pipe. This polarity reversal indicates a possible anodic condition.

B7.5 Surface potential gradients indicating current away from the pipeline on both sides of the pipeline indicate a possible anodic condition. See Figure B2.

B7.6 Surface potential gradients indicating current away from the pipeline on one side and current toward the pipeline on the other side may indicate earth currents across the pipeline. Careful investigation should be conducted to ensure an anodic condition does not exist on the pipeline or that a galvanic anode does not exist.

B7.7 Data may be recorded on a form or recorded using a data logger but special attention should be given to ensure the polarity of each voltage measurement is recorded correctly.

B7.8 Adequate marking or precise survey coordinates (GPS) of anodic conditions are necessary so they can be located for future attention. Additional measurements such as structure-to-electrolyte potentials, soil resistivity, and pH measurements may be made at anodic indications. These tests may be helpful in evaluating the severity of ongoing corrosion, anode current, and anode life.

B8 Data Validity and Post-Job Analysis

B8.1 Erroneous readings must be identified and omitted.

B8.2 The surface potential gradient survey data may be used to generate a structure-to-electrolyte potential gradient curve. The structure-to-electrolyte potential is measured at a test point, such as a test station or pipeline appurtenance. Provided the pipeline is electrically continuous, this value is recorded and becomes the reference value to which all other surface potential gradient measurements are referenced. These potential data can then be plotted as a typical structure-to-electrolyte potential curve. Alternatively, a plot can be made using other reference potentials such as remote earth.

B9 Interpretation of Survey Data

B9.1 This standard does not address interpretation of survey data. Survey data shall be reviewed and interpreted only by persons qualified and experienced in these types of surveys. Interpretation generally considers the following:

- (a) Polarity change of a measured value;
- (b) Magnitude of the value measured;
- (c) Magnitude of the lateral two reference electrode value;
- (d) Soil resistivity, pH, and other environmental characteristics;
- (e) Pipe resistances;
- (f) Galvanic anode locations
- (g) Locations of pipeline laterals or fittings
- (h) Physical location of the pipe with respect to other structures; and
- (i) Known corrosion leak history.

B9.2 Errors in observing instrument polarities, incorrect algebraic calculations, unbalanced reference electrodes, reference electrode placement or pipe location, and poor earth/reference electrode contacts cannot be determined after the survey is complete. Surveys must be conducted by qualified personnel, and inspection or supervision may be necessary to ensure that a valid survey is obtained.

Appendix C: Using Coupons to Determine Adequacy of Cathodic Protection (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.

Note that this is not the only method that may be used, but it does describe a logical use of the information.

C1 Coupons have been used judiciously, particularly when accompanied by other engineering tools and data, to evaluate whether cathodic protection at a test site complies with a given criterion. See ANSI/NACE Standard SP0104 for more information on coupons.¹⁰ It should be noted that a coupon may not duplicate the potential of the structure at the same location, but it will demonstrate whether the CP system has the capacity to provide CP to a coating holiday of equivalent size of the coupon at that location. The following test procedures are suggested as guides.

C1.1 Scope

This method uses a cathodic protection coupon to assess the adequacy of cathodic protection on metallic structures according to the criterion stated in NACE SP0169.³

C1.2 General

C1.2.1 These methods use a coupon to assess the adequacy of cathodic protection applied to a selected test site. A cathodic protection coupon is a metal sample representing the structure at the test site and used for cathodic protection testing. Material, size, shape, and other considerations for the coupon are:

- (a) Nominally of the same metal and surface condition as the structure;
- (b) Small to avoid excessive current drain on the cathodic protection system;
- (c) Placed at structure depth in the same backfill as the structure;
- (d) Prepared with all mill scale and foreign materials removed from the surface;
- (e) Placed at a known location of an ineffective coating when the structure is coated, and;
- (f) Placed at locations that minimize the influence of anode gradients

C2 Cathodic Protection Coupon Test Method 1 – Polarized Structure-to-Electrolyte Potential of Metallic Piping

C2.1 A coupon has an insulated test lead brought above ground and, during normal operations, connected to a pipeline test lead. The coupon receives cathodic protection current and represents a coating holiday on the pipeline at the test site. For testing purposes, this connection is opened, and the polarized potential of the coupon is measured using a high impedance voltmeter with respect to a stationary reference electrode or a portable reference electrode placed inside the coupon station housing and in contact with the internal soil column. The time the connection is open to measure the coupons instant-OFF potential should be minimized to avoid significant depolarization of the coupon. The off period is typically less than 3 seconds. When possible, coupon current direction and magnitude should be verified, using a zero-resistance ammeter, current clip gauge, appropriately sized shunt or resistor permanently placed in series with the coupon lead. Measurements showing discharge of current from the coupon should be reason to question the validity of using a coupon at the test site or it may indicate a corresponding discharge of current from the pipeline.

C2.2 The significance of voltage drops caused by currents from other sources may not be a problem when a coupon is used to represent the pipeline. The coupon's small size may reduce the effect of these voltage drops by reducing the current. The magnitude of these voltage drops can be quantified by interrupting cathodic protection current sources while the coupon is disconnected and noting whether there is a shift in the coupon-to-electrolyte potential.

C2.2.1 The coupon test station housing (as shown in Figure 3 of RP 0104 – 2004 or PRCI PR-186-9220 - Figure 20 or Figure 38) provides an access tube for the measurement of potentials close to the pipeline surface. This proximity minimized the voltage drop errors associated with current through the soil, especially those from detrimental current sources, which are deliberately not interrupted.

C2.3 Comparison of Coupon with Other Methods

C2.3.1 Advantages

- (a) Can provide a polarized coupon-to-electrolyte potential, free of voltage drop, with a minimum of specialized equipment, personnel, and vehicles; and
- (b) Can provide a more comprehensive evaluation of the polarization at the test site than conventional structure-to-electrolyte potential measurements that may be influenced by the location, size, and number of coating holidays, when the pipeline is coated.

C2.3.2 Disadvantage

- (a) Can have high initial costs to install coupons, especially for existing pipelines.

C3 Cathodic Protection Coupon Test Method 2 – Polarization Measurement for Metallic Piping

C3.1 The amount of cathodic polarization can be approximated by comparison of the polarized coupon-to-electrolyte potential (measured as described in Section C2) with a depolarized potential, measured with the same technique, following a period with the coupon disconnected from the pipeline. In accordance with the criterion stated in NACE SP0169, at least 100 mV of cathodic polarization decay will satisfy this CP criterion.

C3.1.1 The length of time that the coupon remains disconnected before measurement of the depolarized potential can vary depending on the characteristics of the pipeline and the electrolyte environment. A high impedance recording voltmeter may be set to provide a record of the polarization decay. Note that the instrument itself may cause accelerated depolarization.

C3.1.2 It is not necessary to allow the coupon to fully depolarize if the 100 mV criterion can be satisfied before this occurs.

Appendix D: Dynamic Stray Current (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.

Introduction

This appendix applies where dynamic stray current conditions have been identified or are anticipated. The most common types of sources for dynamic stray current are telluric currents and DC-operated transit or mine systems.

D1 Telluric Current

D1.1 Introduction

D1.1.1 Telluric current occurs naturally due to geomagnetic fluctuations in the earth. The earth's magnetic field is generally from north to south, but does vary throughout the world. This magnetic field projects into outer space where it is affected by the "solar wind" consisting of solar plasma produced by the sun. The effect is normally greater during the day when the earth has a greater exposure to the sun.

D1.1.2 Should a pipeline be installed in this telluric current activity, a current can either be induced onto the pipe or may enter by conduction. The change in structure-to-electrolyte potentials may only be due to changes in the earth's potential gradient that does not reflect a current pickup or discharge but commonly there is a current associated with it.

D1.2 Procedure

(Note: The following procedure may be used as an approach under mild/moderate telluric conditions)

D1.2.1 To determine a true polarized potential under these conditions, both the voltage error due to the CP current (V_{e-CP}) and that for the telluric current (V_{e-TC}) need to be removed from the reading to establish a true polarized potential. The V_{e-CP} can be removed by simultaneously interrupting the CP current sources and measuring the instant OFF (polarized) potential directly. To remove the V_{e-TC} , the ON and OFF potentials are recorded for a 24-hour period by a stationary datalogger(s) to obtain a base-line potential and to determine the deviation from that base-line at any given time of the survey. The portable datalogger should record for 3 to 5 minutes to enable matching the portable profile to a segment of the stationary datalogger at the same precise time.

D1.2.2 If the test section is short, one stationary datalogger can be used but with longer sections of pipeline to test, two or more dataloggers are deployed. The ON/OFF potentials recorded during a quiet telluric period establishes base-line potentials at that location. The stationary dataloggers (SDL) are time synchronized to the portable datalogger (PDL). The profiles between the stationary and portable dataloggers are matched to the same precise time and by overlapping the profiles.

D1.3 Analysis

D1.3.1 The deviation from the base-line potential ($\pm V_{e-TC}$) is calculated at each PDL location by:

$$V_{TCb} = [V_{TCa}(c - b)/(c-a)] + [V_{TCc}(b - a)/(c-a)] \quad (D1)$$

where:

a = first stationary potential location (meters)

b = portable potential location (meters)

c = second stationary potential location (meters)

V_{TCa} = error in potential at a at time x (Volts) (stationary)

V_{TCb} = error in potential at b at time x (Volts) (portable)

V_{TCc} = error in potential at c at time x (Volts) (stationary)

The stationary dataloggers should record for a 24-hour period with the intent of defining a quiet period for a base-line potential that often occurs at night.

The compensated potential (E_{TCcomp}) is then calculated as:

$$E_{TCcomp} = E_{TC} \pm V_{TCb} \quad (D2)$$

D2 Dynamic Interference Testing of DC Operated Transit or Mine Trains

D2.1 Introduction

D2.1.1 Dynamic stray current interference from DC transit or DC mine trains occurs when a portion of the train's return current, intended to be via the rails, follows a parallel path through the earth and the pipeline. Simultaneously, before mitigation, there will be a current pickup at one location and a current discharge at another location to go back to the track and return to the current source. The points of current discharge from the rails and pickup will change as the trains move along the track making it complex to test and analyze. The point(s) of maximum discharge from the pipe are unlikely to change.

D2.1.2 Where the running rails are the intended path for the return of current to the source (typically, a substation bus), the rails tend to pull current from the surrounding environment, including nearby pipelines, unless a train (load) is present. Local trains often overload the conductivity of the return system, causing the rails to discharge current at locations of reduced contact resistance with the environment.

D2.1.3 More recent rail construction attempts to electrically isolate the rails from the earth. With time, the isolating material may break down or the collection of dirt (road salt) especially at road crossings cause the rail to contact the earth therefore the stray current condition can change over time at any given location. Note that this is an undesirable condition for the rail as a current discharge corrodes it also.

D2.1.4 Dynamic stray current is dependent on the relative locations of the trains and their loads (idling, starting or running) and on the track to earth resistance that will change along the route. Thus, the current densities and current direction at pipeline holidays will vary, so an instantaneous measurement is not expected to be a representative condition. In addition, it will not record the true effect of this stray current.

D2.1.5 Measuring the true structure to electrolyte polarized potentials in presence of dynamic interference from DC operated transit or mine trains is therefore challenging and combinations of methods are often required. Any test method selected should therefore be conducted over the time the trains are operating. Considerations should be made for recording during quiet time. The train schedule through the test area should be recorded.

D2.1.6 The ultimate objective is to ensure that all portions of the pipeline will continue to meet criterion thus establishing a current pickup at all times. Nevertheless, it is critical to minimize periods of overprotection of the structure that could damage the protective coating.

D2.1.7 Personnel conducting these tests are to be experienced or under the supervision of cathodic protection persons experienced in this type of testing and in the analysis of these tests.

D2.2 Procedure: The following procedures are a sampling of the testing techniques that can be applied.

D2.2.1 DC transit or mine train interference can be tested using the Beta Curve technique. The objective is to determine the point of maximum exposure to install a bond, if required.

NOTE: In general, it is best to avoid electrical interconnections (bonds) between a structure and the negative return (running rails or substation bus). Such bonds surrender control of the structure operation to the vagaries of the foreign operator.

D2.2.2 Simultaneously, measure both the pipe-to-electrolyte potential and the pipe-to-track potential using synchronized dataloggers at several test locations for a 24-hour period. During the stray current active period, plot the pipe-to-electrolyte against the pipe-to-track potential at each location tested. The location(s) with a positive slope is the point(s) of maximum exposure.

D2.2.3 In addition, measure the pipe-to-electrolyte potential and the pipe current using synchronized dataloggers at calibrated current measurement spans or clamp-on ammeters at several locations for a 24-hour period. During the active stray current period, plot the potentials against the current for each location. A positive plot will also indicate the point of maximum exposure.

D2.2.4 A comparison of the potential profiles between locations at the same time may also yield some useful information.

D2.3 Correlations of stray current activity along pipeline can be obtained using recording devices with two or more channels (e.g., X-Y plotter data logger. Simultaneous recordings can be plotted to obtain linear equations in the form:

$$V_x = \beta E_s + \alpha \quad (D3)$$

where:

V_x is the structure-to-electrolyte potential at any location along the pipe;

E_s is the source driving potential (typically between the pipe and rail);

β is the slope of the equation

α is the plotted axis intercept when $E_s = 0$

By direct measurement or by algebraic manipulation, a series of equations can be obtained based on common parameter that can be recorded for the complete 24-hour operating pattern. The slopes of these equations can be plotted versus distance along the pipeline to obtain the "Beta-profile," which can identify the locations of greatest influence/activity. These equations permit the calculation of local potential at any test point along the pipeline at any time (e.g., maximum, minimum, quiet) during the 24-hour recording. Similar correlations of current flow along calibrated pipe spans can identify locations of current loss along the pipeline where remedial action may be concentrated.

D3 Dynamic Testing with Coupons

D3.1 The instant-OFF potential of the coupon is not expected to be affected by the dynamic stray current when it is interrupted and the normal test procedure can then be used (see NACE SP0104). However, the ON potential when connected to the structure will be influenced by the stray current thus the voltage error due to cathodic protection current should be determined under quiet stray current conditions.

Similarly, when connected, the coupon current and polarity can vary with dynamic stray current. A monitoring program should include the measurement of the ON potential and coupon current over time.

D3.2 An assessment of cathodic protection under dynamic stray current conditions can be made with coupons and/or soil electrical resistance (ER) corrosion probes. These must be installed in areas of anticipated maximum exposure. When using coupons, it is important to measure instant-OFF potentials with time, so different stray current conditions are monitored. If measuring ON structure-to-electrolyte potentials only, the voltage error in the ON potential must be removed before using the result as a criterion.

D3.3 Coupons can be designed in such a way that the difference between ON and OFF potentials are very low because reference electrodes are located close to their sensitive area or a plastic tube is used to work as a salt bridge. These coupons are known as IR Free or concentric. Ohmic drop can be measured by just interrupting the coupon connection to the structure. If this value is not significant, the ON potential may be considered as a polarized potential. So, it is necessary to take long time potential measurement and assess polarization criteria for different train operation conditions during a typical day.

D4 Use of In-Line Inspection Data

Where the pipeline integrity program includes an in-line inspection (ILI), corrosion features, even minor ones, should be assessed to determine if they may be due to stray current interference. Corrosion is accelerated under these conditions, so a normal corrosion growth rate may not apply.

D5 Stationary Sources of Dynamic Stray Current Interference

The points of maximum exposure of stationary dynamic stray current interference sources can be tested and identified by dataloggers installed through the section of exposure.

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Appendix E: AC Corrosion Testing (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.

The subject of AC corrosion is too complex to address in detail of this document. However, additional information is available in the references listed below.

E1 Although not as aggressive as a similar DC discharge from the structure, a high AC current density can cause AC corrosion on a pipeline if the current density from the pipeline surface is at a high enough current density. The AC current density (i_{AC}) is dependent on several factors, including the AC structure-to-electrolyte voltage (V_{AC}), the soil resistivity (ρ) and the size of the coating holiday.

E1.1 Typically, well coated pipelines are of most concern for induced AC voltages or fault current. Poorly coated or well-grounded pipelines do not hold a sufficient AC voltage. Although 15 V_{AC} is a hazardous voltage limit (See NACE SP0177), a lower voltage can still cause AC corrosion.⁵

- E2** An AC structure-to-electrolyte voltage is measured in the same manner as a structure-to-electrolyte potential except that:
- E2.1** Caution must be taken to use electrically isolated probes, clips and test leads and to not touch an exposed terminal. An RMS AC voltmeter is used. Although a CSE is typically used, any metal can be inserted into the soil as a reference electrode.
- E3** NACE SP0169-2013 indicates in 6.2.1.4.5 that AC corrosion be investigated at a current density of $30 A_{AC}/m^2$ or greater.³
- E4** As it is impractical to measure the AC current at a coating holiday, the following equation can be used to estimate the current density. In the absence of a known coating holiday size, a 1 cm^2 holiday can be assumed. A properly sized coupon test could confirm the following calculation:

$$i_{AC} = (8V_{AC})/\rho\pi d \quad (E1)$$

where:

i_{AC} = AC current density (Amperes_{AC}/m²)

V_{AC} = AC voltage-to-earth (Volts_{AC})

ρ = Soil resistivity (Ω-m)

d = Coating holiday diameter (m)

In the event that i_{AC} exceeds $30 A_{AC}/m^2$, grounding of the pipeline should be considered; and, if greater than $100 A_{AC}/m^2$, it must be considered.

E5 Alternately, the current density calculated from the AC current as measured on a properly placed coupon of a known size can be used to predict i_{AC} by dividing the measured current by the coupon surface area.

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- ISO 18086:2015 Corrosion of Metals and Alloys - Determination of AC Corrosion - Protection Criteria

Appendix F: Evaluation of Potentials Considering Adequacy of Current Interruption (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.

- F1** Polarized potentials of a buried or submerged metallic structure, especially those exposed to outside influences are difficult to measure therefore synchronously interrupting the current and measuring instant OFF potentials are often utilized during field surveys to approximate polarized potentials.
- F2** Frequently, it is difficult to interrupt all current sources that provide CP current to buried or submerged metallic structures. When 100% current interruption cannot be achieved, the accuracy of the structure-to-electrolyte potential recorded during the off cycle (current interrupted) must be evaluated, as the recorded potential will include the instant off potential with a voltage error component associated with the current through the electrolyte even though reduced.
- F3** The instant off potential is not linearly proportional to the current applied as it depends on the environment and whether the structure is under activation or concentration polarization control. This is illustrated by the results of different studies in Tables F1 & F2 and Figure F1.
- F4** Research published by Payer in 2002¹ illustrates the relationship between applied current and polarized potentials. In this study, varying levels of cathodic protection were maintained on steel samples with 0.25-inch coating holidays in a laboratory environment. The tests were conducted in soil over 28 days on multiple samples of fusion bonded epoxy (FBE), polyethylene backed tape, and coal tar enamel coatings at varying polarized potentials. Results were averaged and are summarized in Table F1.
- F5** By comparing Case 1 to Case 2, a ten-fold increase in current density resulted in a change in the polarized potential of -100 mV or, comparing Case 1 to Case 3, 3,000 times the current was required to change the potential by -400 mV.
- F6** Research published in 1980 by the US Air Force Engineering & Services Center at Tyndall Air Force Base² details experiments conducted between 1977 and 1980 to determine and demonstrate the limiting surface potential criteria to be measured over underground and under water facilities to avoid damage to protective coatings from hydrogen evolution. Varying levels of cathodic protection were maintained on steel samples with 0.75-inch coating holidays in a laboratory environment. The tests were conducted in tap water over 28 days on multiple samples of FBE, coal tar enamel, polyethylene backed tape, and asphalt pipe coatings. This research produced the following conclusions.
- F6.1** The most negative OFF potential obtainable was -1.22 Volts_{CSE}. The instant OFF potential could not be made more negative than that value even with a substantial increase in applied current.

Table F1
Payer Research 2002

Case	Average Polarized Potential (CSE)	Average Applied Current	Average Current Density
1	-1 V/-1000 mV	0.001 mA	35.5 mA/m ² (3.3 mA/ft ²)
2	-1.1 V/-1100 mV	0.01 mA	355 mA/m ² (33 mA/ft ²)
3	-1.4 V/-1400 mV	3 mA	107 A/m ² (10 A/ft ²)

Table F2
Husock Research 1980

Case	Average Polarized Potential (CSE)	Average Applied Current	Average Current Density
A	-1.02 V/-1020 mV	0.016 mA	56 mA/m ² (5.2 mA/ft ²)
B	-1.07 V/-1070 mV	0.023 mA	83 mA/m ² (7.7 mA/ft ²)
C	-1.12 V/-1120 mV	0.11 mA	380 mA/m ² (35 mA/ft ²)
D	-1.17 V/-1170 mV	1.34 mA	4.7 A/m ² (435 mA/ft ²)
E	-1.22 V/-1220 mV	5.45 mA	19 A/m ² (1775 mA/ft ²)

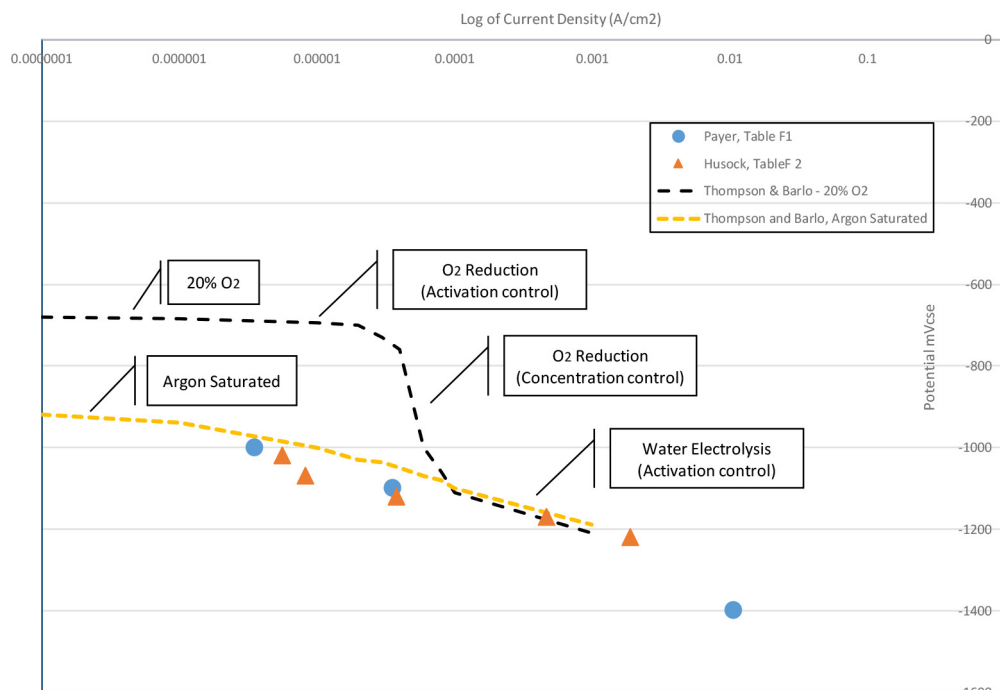


Figure F1: Comparison of Potential versus Current Density from Research Studies

F6.2 An increase in the current-applied to a specimen at an instant OFF potential of -1.22 Volts_{CSE} resulted in increased hydrogen evolution and an increase in the negative ON potential, but the OFF potential remained unchanged.

F6.3 The OFF potential could not be directly related to the ON potential and, therefore, the ON potential is not considered to be a valid indicator of hydrogen evolution.

F7 A summary of the data is given in Table F2.

F8 The non-linear relationship between structure-to-electrolyte potentials and applied current, results are similar.

F9 Figure F1 summarizes the research study by Thompson and Barlo⁽⁵⁾ on the relationship between the potential and current density with polarization under activation control or concentration control and when exposed to 20% oxygen or without oxygen. The results in Tables F1 and F2 have also been plotted in Figure F1 for comparison.

F10 As noted in the research above and by Barlo and Fessler,⁽⁶⁾ polarized potentials more electronegative than approximately -1250 mV_{CSE} require a large current density increase to cause a change in the potential. The research conducted by Barlo and Fessler on buried coupons also unexpectedly encountered an upper CP limit in field testing of about -1.15 Volts_{CSE}.

F11 Practical limitations on the available current capacity of field CP systems typically limit polarized potentials on pipelines to an electronegative potential limit of approximately -1.20 Volts_{CSE}. Potentials more electronegative than this value may indicate that all current sources have not have been interrupted.

F12 Conclusions of this work are:

F12.1 The error associated with an instant off potential collected when current interruption less than 100% must be carefully evaluated with an understanding of the possible voltage error due to the remaining current being applied.

F12.2 An evaluation should carefully review any instant-off potential more electronegative than approximately -1,200 mV_{CSE} to verify that there was adequate current interruption.

⁽⁵⁾ N.G. Thompson and T.J. Barlo, "Fundamental Processes of Cathodically Protecting Steel Pipelines," Gas Research Proceeding, presented 1983 (Rockville, MD: Government Institutes, Inc.).

⁽⁶⁾ Barlo, T. and Fessler, R., Interpretation of True Pipe-to-Soil Potentials on Coating Pipelines with Holidays, Corrosion 83, Paper No. 292, 1983.

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