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Standard Practice

Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines

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Foreword

This standard practice presents procedures for performing close-interval direct current (DC) structure-to-electrolyte potential surveys, DC surface potential gradient surveys, and hybrid surveys such as trailing-wire direct current voltage gradient (DCVG) surveys or intensive measurement surveys, on buried or submerged metallic pipelines. Cell-to-cell surveys used to evaluate coating effectiveness are described in other NACE publications.[1]

This standard is intended for use by corrosion control personnel involved with operating pipelines, contractors performing close-interval survey (CIS) and other surveys, corrosion professionals interpreting CIS and other survey data, and regulatory agencies. Included are definitions, pre-job considerations, instrumentation and equipment guidelines, methods for IR drop correction, pipe location and marking procedures, survey procedures, hybrid survey procedures, offshore and dynamic stray-current survey procedures, cell-to-cell surface potential gradient surveys, and data validity and post-job considerations.

For accurate and correct application, this standard must be used in its entirety. Using or citing only specific paragraphs or sections can lead to misinterpretation and misapplication of the recommendations and practices presented. Specific practices are not designated for every situation because of the complexity of conditions to which buried or submerged piping systems are exposed.

This standard was prepared by Task Group (TG) 279 on Pipelines: Close-Interval Potential Surveys on Buried or Submerged Metallic Pipelines. TG 279 is administered by Specific Technology Group (STG) 35 on Pipelines, Tanks, and Well Casings, and sponsored by STG 05 on Cathodic/Anodic Protection. This standard is issued by NACE International under the auspices of STG 35.

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, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term *should* is used to state something good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

NACE International
Standard Practice

Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines

Contents

Section 1: General

1.1 Introduction

1.1.1 This standard defines the requirements for performing close-interval potential surveys and DC surface potential gradient surveys on buried or submerged metallic pipelines. For the purposes of this standard, the terms close-interval potential survey (CIPS) and close-interval survey (CIS) are used interchangeably. Procedures for performing hybrid close-interval surveys are given in Section 8. Procedures for performing CIS in marine conditions are given in Section 9. Considerations for dynamic stray current are given in Section 10. Procedures for performing DC cell-to-cell surface potential gradient surveys are given in Section 11. Methods for calculating the net current based on measured voltage drop and pipeline geometry are included in Appendix A (nonmandatory).

1.2 Scope

1.2.1 CIS is used to designate a potential survey performed on a buried or submerged metallic pipeline, in order to obtain valid DC structure-to-electrolyte potential measurements at a regular interval sufficiently small to permit a detailed assessment.

1.2.1.1 Types of CIS include data collection prior to application of cathodic protection (CP) (native-state survey), as well as data collection with the CP systems in operation ("on" survey), with the CP current sources synchronously interrupted (interrupted or "on/off" survey), with asynchronous interruption of CP current (waveform analyzer survey), and with CP currents turned off for some time to allow the structure to depolarize (depolarized survey).

1.2.2 A hybrid survey is a CIS combined with other types of measurements such as side drains, lateral potentials, or cell-to-cell surface potential gradients along the pipeline.

1.2.2.1 This standard addresses hybrid survey techniques such as trailing-wire DCVG or intensive measurement surveys (CIS with side drains).

1.2.3 Surface potential gradient surveys are a series of surface potential gradients measured along or normal (perpendicular) to a pipeline.

1.2.3.1 This standard addresses DC cell-to-cell surface potential gradient surveys (e.g., hot-spot surveys, side-drain surveys) used to evaluate the direction of current in the earth and to identify possible anodic areas on a pipeline. AC-voltage gradient surveys (such as ACVG) and cell-to-cell surveys (such as traditional DCVG) used to evaluate the effectiveness of the coating are described in other NACE publications.[1]

1.2.4 This standard includes procedures to perform these types of surveys along a buried or submerged pipeline. The standard acknowledges that all potential measurements contain error, and includes some guidance to minimize the error in each measurement. The standard does not address interpretation of survey data. A qualified person must determine whether the data contain an acceptable amount of error and can be used to evaluate the level of cathodic protection.

1.3 Qualifications

1.3.1 The provisions of this standard should be applied under the direction of competent persons who, by reason of knowledge of the physical sciences and the principles of engineering and mathematics acquired by education and related practical experience, are qualified to engage in the practice of corrosion control on buried or submerged metallic piping systems. Such persons may be registered professional engineers or persons recognized as Corrosion Specialists, CP Specialists, or Corrosion or CP Technologists by NACE if their professional activities include suitable experience in the collection and evaluation of these types of data used to monitor external corrosion control of buried or submerged metallic piping systems.

1.3.2 Persons performing these types of surveys (for the purposes of this standard, called surveyors) must be qualified to understand and follow the applicable procedures contained in this standard or work under the direct supervision of a person that is qualified. Such persons may be recognized as NACE CP Testers, Corrosion or CP Technicians, Technologists, Specialists, or equivalent if their professional activities include suitable experience in performing surveys of buried or submerged metallic piping systems.

1.4 Survey Impediments

1.4.1 Certain conditions can make the data from a survey difficult to interpret properly, or make the survey impractical to perform. Examples include:

1.4.1.1 Areas of high contact resistance:

1.4.1.1.1 Pipe located under concrete or asphalt pavement—Contact resistance may be reduced by drilling through the paving to permit electrode contact with the soil (see Paragraph 7.3.2).

1.4.1.1.2 Frozen ground—Contact resistance may be reduced by removing the frozen soil to permit electrode contact with unfrozen soil (e.g., drilling), or heating the soil to the melting point of water. Because this is often difficult or impractical, surveys should be scheduled, when possible, to avoid unfavorable seasons.

1.4.1.1.3 Very dry conditions—If the surface soil is dry enough to cause the electrical contact of the reference electrode with the electrolyte to be impaired, the soil around the electrode may be moistened with water until the contact is adequate (see Paragraph 7.3.4.6). Because this is often difficult or impractical, surveys should be scheduled, when possible, to avoid unfavorable seasons.

1.4.1.2 Adjacent buried or submerged metallic structures;

1.4.1.3 Surface conditions limiting access to the electrolyte:

1.4.1.3.1 Backfill with significant rock content or rock ledges;

1.4.1.3.2 Gravel; and

1.4.1.3.3 Dry vegetation.

1.4.1.4 Telluric or other dynamic stray currents;

1.4.1.5 High levels of induced alternating current (AC) that could influence potential measurements or present a safety hazard;

1.4.1.6 Pipelines buried very deep;

1.4.1.7 Locations at which coatings cause electrical shielding; and

1.4.1.8 Lack of electrical continuity, such as with some forms of mechanically coupled pipe that have not been made electrically continuous through the use of bonding cables or straps welded across each coupling.

1.5 Applications of Surveys

1.5.1 CIS provides a detailed assessment of CP system performance and operation in accordance with established criteria for CP such as those in NACE SP0169.[2] A near-continuous evaluation is possible when performed with a suitable survey interval (see Paragraph 7.2.1).

1.5.2 The objective of a CIS is to measure the structure-to-electrolyte potential at sufficient points along a pipeline. Interpreting the data can provide additional benefits such as:

1.5.2.1 Identifying areas outside the range of potential criteria of a pipeline not identified by test point surveys;

1.5.2.2 Determining the extent of areas outside the range of potential criteria;

1.5.2.3 Locating medium-to-large defects in coatings (isolated or continuous and typically >600 mm^2 [1 in.^{2}])[1];

1.5.2.4 Locating areas of stray-current pickup and discharge or at risk for interference corrosion;

1.5.2.5 Determining the area of influence of CP;

1.5.2.6 Identifying possible shorted casings, defective electrical isolation devices, or unintentional contact with other metallic structures;

1.5.2.7 Locating areas of geologic shielding of CP;

1.5.2.8 Measuring the level of CP in conducting current demand testing, and evaluating the effectiveness of current distribution along a pipeline;

1.5.2.9 Locating possible high-pH stress corrosion cracking (SCC) risk areas: the level of CP has been shown to be a factor in the susceptibility of pipelines to high-pH SCC. CIS may assist in locating areas along a pipeline at which structure-to-electrolyte potentials fall in the susceptibility range for SCC; and

1.5.2.10 Locating and prioritizing areas of risk of external corrosion as part of an integrity management program, or a component of an external corrosion direct assessment (ECDA).

1.5.3 DC cell-to-cell surface potential gradient surveys may be used to evaluate the direction of current in the earth and to identify possible anodic areas on a pipeline.

1.5.3.1 Side-drain or lateral potentials may also be used to extrapolate IR free measurements when only a portion of the IR drop is interrupted.[3]

1.5.4 Hybrid surveys may provide additional information to a CIS in order to interpret the data and evaluate the external corrosion control of a pipeline.

Section 2: Definitions

Aboveground Marker (AGM): A portable or permanently installed device placed on the surface above a pipeline that both detects and records the passage of an in-line inspection (ILI) tool or transmits a signal that is detected and recorded by the tool.

AC Rejection: Measure of the influence of AC voltages on DC potential measurements by a voltmeter.

Alternating Current Voltage Gradient (ACVG) Survey: A method of measuring the change in leakage current in the soil along and around a pipeline to locate coating holidays and characterize corrosion activity.

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.

Anomaly: An unexamined deviation from the norm in pipe material, coatings, or welds.

Appurtenance: A component that is attached to the pipeline; e.g., valve, tee, casing, instrument connection.

Automatic Potential Controlled (APC) Rectifier: See *Constant Potential Controlled Rectifier*.

Bond (also Continuity Bond): A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity.

Cable: A bound or sheathed group of insulated conductors.

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

Cathodic Disbondment: The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.

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

Cathodic Protection (CP) Coupon: A metal specimen made of similar material as the structure under investigation, which is connected to the external surface of, and immersed in the electrolyte adjacent to, the structure being protected by cathodic protection.

Cell-to-Cell Survey: A survey measuring the potential difference between two reference electrodes. Cell-to-cell surveys include ACVG, DCVG, side-drain, and hot-spot surveys.

Close-Interval Potential Survey (CIPS) (also Close-Interval Survey [CIS]): A potential survey performed on a buried or submerged metallic pipeline, in order to obtain valid DC structure-to-electrolyte potential measurements at a regular interval sufficiently small to permit a detailed assessment.

Close-Interval Survey with Laterals: A hybrid survey that simultaneously measures the structure-to-electrolyte potentials and the potential at a point lateral to the pipeline.

Coating: A liquid, liquefiable, or mastic composition that, after application to the surface, is converted into a solid protective, decorative, or functional adherent film. For the purposes of this standard, coating refers to a dielectric material applied to a structure to separate it from the environment.

Coating Fault: Any imperfection or defect in the coating, including disbonded areas and holidays.

Conductor: A material suitable for carrying an electric current. It may be bare or insulated.

Constant Current Controlled Rectifier: A rectifier with circuitry and controls to maintain a constant current output.

Constant Potential Controlled Rectifier: A rectifier with circuitry and controls to maintain a constant level of potential on a structure.

Contact Point: A location at which an electrical connection can be made with the pipeline, such as a test lead or aboveground pipe or appurtenance.

Contact Resistance: Electrical resistance at the interface between the reference electrode and the electrolyte.

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

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: Standard for assessment of the effectiveness of a CP system.

Current Density: The current to or from a unit area of an electrode surface.

Current Interrupter: A device that interrupts CP current.

Defect: A physically examined anomaly with dimensions or characteristics that exceed acceptable limits.

Depolarization: The removal of factors resisting the current in an electrochemical cell. For the purposes of this standard, depolarization refers to a reduction in the level of protection due to a reduction or elimination of cathodic protection current.

Depolarized Close-Interval Potential Survey: A CIS performed after influencing CP current sources have been turned off for a sufficient duration of time for depolarization to have occurred. This is often called a native-state CIS if it is performed prior to the initial application of CP.

Differential Global Positioning System (DGPS): Global Positioning System survey using differential error correction in order to obtain more accurate positioning.

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

Disbonded Coating: Any loss of adhesion between the protective coating and a pipe surface as a result of adhesive failure, chemical attack, mechanical damage, hydrogen concentrations, etc. Disbonded coating may or may not be associated with a coating holiday. See also *Cathodic Disbondment*.

Downstation: In the direction of increasing station number or kilometer post (KP)/milepost (MP).

Downstream: In the direction of flow.

Drop-Cell Survey: CIS of conventional submerged vertical riser.

Duty Cycle: The ratio of the duration CP current is applied to the duration CP current is interrupted.

Dynamic Stray Current: Stray current with changing amplitude and/or geographical path.

Electrical Connection: Point at which the structure is metallically connected to the measurement circuit.

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

Electrical Survey: Any technique that involves coordinated electrical measurements taken to provide a basis for deduction concerning a particular electrochemical condition relating to corrosion or corrosion control.

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

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 adjacent to and in contact with a buried or submerged metallic piping system, including the moisture and other chemicals contained therein.

External Corrosion Direct Assessment (ECDA): A four-step process that combines pre-assessment, indirect inspections, direct examinations, and post assessment to evaluate the impact of external corrosion on the integrity of a pipeline.

Far-Ground (FG) Potential: A structure-to-electrolyte potential measured directly over the pipeline, away from the electrical connection to the pipeline.

Fast-Cycle Interruption: An interruption cycle in which the “off” cycle is less than one second. Usually used so that both an “on” and an instant-off structure-to-electrolyte potential can be measured at each measurement location.

Fast-Cycle Survey: An interrupted CIS using fast-cycle interruption.

Field Comments: Comments entered by the surveyor during the CIS.

Field Plots: CIS graphs generated during the survey.

Flag: A pin flag, or the interval that the flag represents, generally 30 m (100 ft).

Footer Information: Set of comments, measurements, and other information entered at the end of a survey run.

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

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 electron source in one type of CP.

Global Positioning System (GPS): The navigational system utilizing satellite technology to provide a user a position on the earth’s surface.

Header Information: Set of comments, measurements, and other information entered at the start of a survey run.

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

Hot-Spot Survey: A cell-to-cell surface potential gradient survey consisting of a series of potential gradients measured along the pipeline, often used on pipelines that are not electrically continuous or on bare or ineffectively coated pipelines in order to detect the probable current discharge (anodic) areas along a pipeline. Where the pipeline is electrically continuous, a close-interval survey and lateral potentials will also detect areas of probable current discharge (anodic areas).

Imperfection: An anomaly with characteristics that do not exceed acceptable limits.

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 CP.)

In-Line Inspection (ILI): The inspection of a steel pipeline using an electronic instrument or tool that travels along the interior of the pipeline.

Indication: Any deviation from the norm as measured by an indirect inspection tool such as CIS. An indication may be further classified or characterized as an anomaly or imperfection.

Input Impedance: The equivalent electrical impedance of a voltmeter's internal circuitry in the measurement circuit.

Input Resistance: The equivalent electrical resistance of a voltmeter's internal circuitry in the measurement circuit.

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

Intensive Measurement Survey: A hybrid survey that simultaneously measures the structure-to-electrolyte potentials and the potential difference between reference electrodes perpendicular to the pipeline. This survey is also known as a CIS with side drains.

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

Interference Bond: An intentional metallic connection, between metallic systems in contact with a common electrolyte, designed to control electrical current interchange between the systems.

Interrupted Close-Interval Potential Survey (On/Off Survey): A series of structure-to-electrolyte potentials taken along a pipeline, with influencing CP current sources switched using equipment designed to interrupt the CP current briefly.

Interrupter: See *Current Interrupter*.

Interruption Cycle: Duration of current interruption in the "on" and "off" cycle.

Interval: See *Survey Interval*.

IR Drop: The voltage across a resistance in accordance with Ohm's Law.

Irregularity: See *Indication*.

Isolation: See *Electrical Isolation*.

Lateral Potentials: Structure-to-electrolyte potentials offset to each side of the pipeline, typically at a distance of approximately two and one-half times the pipe depth.

Line Current: The direct current flowing on a pipeline.

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

Long-Line Current Voltage Drop Error: The voltage drop error in the instant-off potential caused by current in the soil due to potential gradients along the pipe surface.

Metallic IR Drop: Component of IR drop that occurs in the metallic path of the measurement circuit, primarily in the pipeline, under normal conditions.

Near-Ground (NG) Potential: A structure-to-electrolyte potential taken directly over the pipeline, at the spot of electrical connection.

"Off" Cycle: The period of time CP current is interrupted during one cycle of interruption.

"Off" Potential: See *Instant-Off Potential*.

"On" Close-Interval Potential Survey: A series of structure-to-electrolyte potentials taken along a pipeline with the CP current applied.

"On" Cycle: The period of time CP current is applied during one cycle of interruption.

"On" Potential: A potential measured with CP current applied.

Open-Circuit Potential: The potential of an electrode measured with respect to a reference electrode or another electrode in the absence of current.

Pipe-to-Electrolyte Potential: See *Structure-to-Electrolyte Potential.*

Pipe-to-Soil Potential: See *Structure-to-Electrolyte Potential.*

Pipe-to-Water Potential: See *Structure-to-Electrolyte Potential.*

Plug: The porous tip of a reference electrode.

Point of Intersection (PI): A change in direction of a pipeline.

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.

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. Examples include saturated copper/copper sulfate (CSE), saturated calomel (SCE), and silver/silver chloride (Ag/AgCl).

Reference Half-Cell: See *Reference Electrode*.

Remote Earth (also Electrically Remote): A location on the earth far enough from the affected structure that the soil potential gradients associated with currents entering the earth from the affected structure are insignificant.

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

Rise Time: Time required for a voltmeter to measure a potential accurately after switching.

Run: See *Survey Run*.

Saturated: A solution obtained when a solvent (liquid) can dissolve no more of a solute (usually a solid) at a given temperature and pressure.

Scatter: Erroneous potentials, usually caused by contact resistance.

Shielding: (1) Protecting; protective cover against mechanical damage [not applicable to this standard]. (2) Preventing or diverting CP current from its natural path.

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

Side-Drain Potentials: Surface potential gradients measured 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 Potential Survey: A cell-to-cell surface potential gradient survey consisting of a series of side-drain potentials measured along a pipeline.

Skip: A section of pipeline that is not surveyed during a CIS, for whatever reason.

Slow-Cycle Interruption: An interruption cycle in which the "off" cycle is greater than or equal to one second.

Slow-Cycle Survey: An interrupted CIS using slow-cycle interruption.

Spiking: A momentary surging of potential that occurs on a pipeline when the protective current from an operating CP device is interrupted or applied.

Station Number: Distance information from a reference on the pipeline, used to locate a point on a pipeline.

Stationing: See *Station Number.*

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

Stray-Current Corrosion: Corrosion resulting from current through paths other than the intended circuit, e.g., by any extraneous current in the earth.

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.

Surface Potential Gradient: Change in the potential on the surface of the ground with respect to distance.

Surface Potential Gradient Survey: A series of surface potential gradients measured along or normal (perpendicular) to a pipeline. Surface potential gradient surveys include DCVG, ACVG, hot-spot surveys, and side-drain surveys.

Survey Direction: The direction a CIS is conducted along a pipeline, usually expressed as upstation or downstation.

Survey Interval: The specified distance between potential measurements along the pipeline in a CIS.

Survey Run: The set of data associated with a single electrical connection to the structure, usually the measurements from one test lead to the next.

Survey Wire: Insulated wire, usually copper, used to connect a survey instrument to the pipeline during a CIS.

Surveyor: Person conducting the CIS.

Synchronized Survey: An interrupted CIS in which the CP current sources are all switched simultaneously.

Telluric Current: Current in the earth as a result of geomagnetic fluctuations.

Telluric Survey: A survey that uses techniques such as listed in Section 10 to correct for telluric currents.

Test Lead (**also Test Station, Test Post**)**:** A wire or cable attached to a structure for electrical connection of a survey instrument to make CP potential or current measurements.

Trailing-Wire DCVG: A hybrid survey that simultaneously measures the structure-to-electrolyte potentials and the potential difference between reference electrodes along the pipeline.

Upload: To send data from the field data acquisition system to a personal computer (PC).

Upstation: In the direction of decreasing station number or KP/MP.

Upstream: In the direction opposite to the direction of flow.

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: See *Spiking.*

Voltmeter Accuracy: The capability of the instrument to faithfully indicate the value of the measured signal. This term is not related to resolution; however, it can never be better than the resolution of the instrument. For example, a 5 1/2 digit voltmeter can have an accuracy of 0.0125% of reading + 24 µV on its 2.5-V range, which results in an error of 149 µV when measuring a 1-V signal. On the other hand, the resolution of this same voltmeter is 12 µV, 12 times better than the accuracy.[4]

Voltmeter Resolution: The smallest amount of input signal change that the instrument can detect reliably. For example, if a voltmeter has 5 1/2 digits displayed and is set to the 20-V input range, the resolution of this voltmeter is 100 µV. This can be determined by looking at the change associated with the least significant digit.[4]

Voltmeter Sensitivity: The smallest signal the instrument can measure. For example, a meter with a lowest measurement range of 10 V may be able to measure signals with 1-mV resolution but the smallest detectable voltage it can measure may be 15 mV. In this case, the meter has a resolution of 1 mV but a sensitivity of 15 mV.[4]

Waveprint: A digitized oscilloscopic plot of the structure-to-electrolyte potential over time, usually recorded during interruption for one or two interruption cycles.

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

Wire Counter: A device that measures distance surveyed based on the length of wire spooled out.

Section 3: Pre-Job Considerations

3.1 Introduction

3.1.1 This section discusses pre-job considerations. Close-interval surveys and surface potential gradient surveys are performed in a wide variety of conditions and for a wide variety of reasons. The pre-job considerations may vary depending on the type and purpose of the survey. These safety recommendations are typical considerations and shall not be construed as taking precedence over recognized safety practices or as a substitute for a comprehensive safety program.

3.2 Pre-job analysis

3.2.1 Surveyors shall review the scope for the project. When appropriate, surveyors shall review expectations for communication, including periodic review of the data during the survey.

3.2.1.1 Arrangements should be made for periodic review of the data, such as examining field plots, by the appropriate person(s) qualified to evaluate survey data for data validity and completeness.

3.2.1.1.1 Consideration should be given to evaluating the data contemporaneous to conducting the survey so that areas may be resurveyed, if required, without reinstalling equipment or re-mobilizing crews.

3.2.1.2 Information about the system should be presented to the surveyor. This information may include:

3.2.1.2.1 Information about the structure and conditions to be surveyed:

(a) Engineering station (and/or KP/MP) of test leads and features;

(b) Line names and identification (e.g., size and line numbers);

(c) Product being transported and direction of flow;

(d) Pipe diameter and wall thickness;

(e) Method of pipe joining (if other than welding);

(f) Coating information;

(g) Pipeline system maps;

(h) Pipeline alignment sheets;

(i) Terrain including type of crops;

(j) Water crossings;

(k) Paved areas;

(l) Anticipated soil moisture;

(m) Depth of cover; and

(n) Geodetic data.

3.2.1.2.2 CP operating data:

3.2.1.2.2.1 Test station survey data;

3.2.1.2.2.2 CP current source information, including influencing foreign CP systems such as:

(a) Type;

(b) Identification;

(c) Output; and

(d) Location.

3.2.1.2.2.3 Identification, type, and location of bonds; and

3.2.1.2.2.4 Identification, type, and location of electrical isolation devices.

3.2.1.2.3 Dynamic stray current information including:

(a) Known stray current sources;

(b) AC mitigation systems; and

(c) Parallel overhead power lines.

3.2.1.3 Other useful information:

(a) Emergency operating maps;

(b) Ingress and egress to rights-of-way;

(c) Known landowner issues;

(d) Historical CIS and other survey data; and

(e) Previous integrity assessments.

3.3 Other pre-job considerations

3.3.1 Coordination may be necessary to ensure that rights-of-way are sufficiently clear for surveying operations.

3.3.2 Rivers, lakes, ponds, swamps, and other bodies of water may require special equipment or vehicles such as boats, swamp buggies, air boats, or other equipment to survey. To minimize the time required to hold specialized equipment, these locations may be skipped and surveyed together. Additional safety considerations and safety equipment may be required for specialized equipment.

3.3.3 Additional tools and equipment may be necessary for drilling through concrete or asphalt pavement.

3.3.4 Other types of surveys may be performed concurrently, as long as the accuracy of the surveys is not affected, including:

(a) Soil or water characteristics such as pH, resistivity, moisture content, and salinity;

(b) Topography and land usage;

(c) Coating surveys such as DCVG;

(d) Side-drain or hot-spot surveys;

(e) Depth-of-cover-surveys, profiles, and identification of locations with exposed pipe;

(f) Identification of infringement on or encroachment of rights-of-way;

(g) Leak detection and identification of leak locations;

(h) Land surveys (conventional, GPS, or DGPS), and

(i) Other surveys that could provide information helpful to evaluating the CIS data.

3.3.5 It may be necessary to obtain permission to interrupt or de-energize foreign CP current sources that influence areas of the pipeline segment being surveyed prior to initiating the survey.

3.3.6 If the pipeline is newly constructed or the CP system has recently been energized, repaired, modified, or adjusted, it may be necessary to allow sufficient time prior to initiating the survey to ensure potentials have stabilized.

3.3.7 If the objective of the survey is to determine the level of CP during normal operations, the survey should be performed with the CP systems operating under normal conditions, and bonds should not be disconnected or the outputs of the protective systems increased or decreased except to compensate for changes due to current interruption.

3.4 Safety

3.4.1 Appropriate safety and regulatory precautions, including the following, shall be observed when electrical measurements are made.

3.4.1.1 Users shall be qualified before installing, adjusting, repairing, removing, or testing impressed-current CP equipment.

3.4.1.2 Appropriate personal protection equipment (PPE) should be used as applicable.

3.4.1.3 Properly insulated test lead clips and terminals should be used to avoid contact with unanticipated high voltage. Insulated test lead clips and terminals must be rated for the highest anticipated voltage that will be encountered during the survey. Test clips should be attached one at a time using a single-hand technique for each connection.

3.4.1.4 Caution should be used when long test leads are extended near overhead high-voltage power lines. Hazardous voltages can be induced onto the test leads. Users should refer to NACE SP0177[5] for additional information.

3.4.1.4.1 Caution should be used when long survey wires are extended when ascending or descending hills to avoid contacting overhead power lines with the test wires. Wire should be properly anchored to ensure that it remains on the ground. Anchors must be nonconducting or electrically isolated from the wire.

3.4.1.5 Caution should be used when conducting tests at electrical isolation devices. Appropriate voltage detection instruments or voltmeters with insulated test leads should be used to determine whether hazardous voltages exist before proceeding with further tests.

3.4.1.6 Testing should be avoided when thunderstorms are in the area. Remote lightning strikes can create hazardous voltage surges that travel along the pipe under the test.

3.4.1.7 Caution should be used when working near streets, roads, and other locations subject to vehicular and pedestrian traffic. Appropriate measures such as barricades, flagging, high-visibility clothing, and flag persons should be used when conditions warrant or as required by the safety or regulatory agency responsible for governing traffic control.

3.4.1.8 Project-specific safety considerations should include, but are not limited to, the following factors:

(a) Potentially hazardous wildlife, including plants and insects indigenous to the area, including identification, avoidance procedures, and emergency procedures;

(b) hunting/trapping seasons, including limited visibility and high-visibility clothing;

(c) considerations for marine surveys and the use of specialized equipment;

(d) environmental extremes, including heat and cold; and

(e) communications with survey crews and emergency personnel.

3.4.1.9 Appropriate company safety procedures, electrical codes, and applicable safety regulations should be observed.

Section 4: Instrumentation and Equipment

4.1 Introduction

4.1.1 This section describes requirements and recommendations for instrumentation and equipment to perform CIS and surface potential gradient surveys.

4.1.2 Structure-to-electrolyte potential measurements in a CIS and surface potential gradient surveys require proper survey meters, reference electrodes, and electrical connections to be valid.

4.1.3 The surveyor must know the capabilities and limitations of the equipment, follow the manufacturer's instruction manual(s), and be skilled in the use of electrical instruments. Failure to select and use instruments correctly can cause errors in measurements.

4.2 Survey meter

4.2.1 The meter shall be sufficiently accurate to measure potentials to an accuracy of an acceptable degree of error in the appropriate range(s) used for structure-to-electrolyte potentials or DC cell-to-cell potential measurements. A typical specification may allow ±1 mV at the largest expected potential measurement, compared to a source of known accuracy or traceable to a recognized standard.

4.2.2 The meter shall have sufficient sensitivity and resolution to measure potentials accurately in the appropriate range(s) used for structure-to-electrolyte potentials. A typical specification may allow a maximum sensitivity and resolution of 1 mV at the highest range.

4.2.3 The meter shall have sufficient AC rejection so that errors to DC potential measurements caused by AC potentials are acceptable. A typical specification may allow less than 5 mV AC ripple at 15 VAC (-70 dB), but may be much more stringent for conditions with higher induced AC potentials.

4.2.4 The meter shall have adequate input resistance to minimize errors caused by contact resistance and other errors in the measurement circuit. A typical specification may require 10 MΩ or greater for surveys in soil, and may contain much higher requirements for conditions with significant contact or other measurement circuit resistances.

4.2.4.1 Resistance of the circuit may be measured using an appropriate resistance meter.

4.2.4.2 Another method of determining the necessary input resistance is adjusting the input resistance on a variable input resistance meter to obtain the minimum input resistance without influence on the potential measurements.

4.2.4.3 Tests may be made at various points showing that the error introduced is acceptable.

4.2.5 For interrupted surveys, the method and equipment shall differentiate the "on" and instant-off potentials in an appropriate manner, if potentials are identified as such, and avoid the effects of transition.

4.2.6 Meters used for fast-cycle interrupted surveys have additional requirements.

4.2.6.1 The meter shall have an appropriate method to ensure the effects of any spiking on the potential measurements are within an acceptable degree of accuracy.[6]

4.2.6.2 Meter rise time shall be adequate in order for the effects of the switching transition on the measurements to be within an acceptable degree of accuracy.

4.2.7 Meters used for asynchronous interrupted surveys have additional requirements.

4.2.7.1 The meter shall use an appropriate method to correct for IR drop in the potential measurements.[7]

4.2.8 Meters must be rugged enough for field use, battery life must be sufficient to conduct a survey without influence on the measurements, and the meter or data logger must have sufficient data storage when applicable. Meters should have overload protection adequate to expected conditions. Meters must maintain the requirements of this section in the handling conditions and ambient climate and temperature conditions of the CIS.

4.3 Meter polarity

4.3.1 Structure-to-electrolyte potentials are usually measured by connecting the instrument negative terminal to the reference electrode that is in contact with the pipe electrolyte and the positive terminal to the pipe.

4.3.2 Structure-to-electrolyte potential measurements are sometimes made with the pipeline connected to the instrument negative terminal and the reference electrode to the positive terminal.

4.3.3 The meter shall indicate the polarity of the measured potential. Meters can be connected in either polarity, but data shall clearly indicate the polarity of the potentials vs. the reference, and clearly identify polarity reversals.

4.4 Reference electrodes

4.4.1 If saturated copper-copper sulfate (CSE) reference electrodes are used, a saturated solution of copper-copper sulfate shall be maintained in each reference electrode.

4.4.1.1 Reference cell solutions such as gel or antifreeze are acceptable if they meet the requirements of Paragraph 4.4.3, when compared to a reference electrode using a standard saturated solution.

4.4.2 In marine or marsh areas with salt or brackish water, silver-silver chloride (Ag/AgCl) reference electrodes should be used. If a CSE is used in a high-chloride environment, the stability (lack of contamination) of the CSE must be determined before the measurements may be considered valid.[8]

4.4.2.1 If other types of reference electrodes are used, they shall be evaluated for suitability with the environment and survey conditions.

4.4.2.2 Appropriate notation shall be made in the data if reference electrodes other than saturated CSE are used.

4.4.3 All reference electrodes must be calibrated periodically with an uncontaminated reference electrode to ensure accuracy according to NACE Standard TM0497.[9]

4.4.3.1 The accuracy of a field reference electrode can be verified by placing it along with the master reference electrode in a common solution such as fresh water, and measuring the voltage difference between the two electrodes. A maximum voltage difference of 5 mV between a master reference electrode and another reference electrode of the same type is usually satisfactory for pipeline potential measurements. Any reference electrodes that do not meet these requirements shall be rebuilt and recalibrated, or replaced.

4.4.4 Reference electrodes that are submerged or placed in an aqueous environment that covers the electrical connection between the reference electrode and the voltmeter leads shall have a waterproof connection to prevent erroneous measurements.

4.4.5 Photo-sensitive measurement error (in CSE with a clear-view window) as a result of light striking the electrode's electrolyte solution (photovoltaic effect) shall be eliminated by covering any windows in reference electrodes with opaque material such as electrical tape.[10]

4.4.6 Temperature correction must be applied to reference electrode potentials when variations in ambient temperatures during the survey significantly affect potentials.[10]

4.5 Electrical connections

4.5.1 All electrical connections shall be made in a manner that establishes a low-resistance (metal-to-metal) electrical connection that is mechanically sound.

4.5.1.1 The wire insulation shall be sufficiently removed for a low-resistance electrical connection when attached to the test lead or structure.

4.5.2 Electrical connections for pipeline potential measurements shall not be made at CP current source negative return cables, galvanic anode leads, bond wires, or other connections that carry significant current.

4.5.3 Electrical connections must be made with appropriate gauge wire to minimize measurement circuit resistance. A typical specification may require copper wire 0.16-mm diameter (34 AWG) or larger; a larger gauge of wire with an appropriate insulation is often required for offshore surveys.

4.5.4 The measurement circuit must be electrically isolated from any path to ground, including the surveyor.

4.5.4.1 The survey wire must have suitable insulation to isolate the wire from the electrolyte.

4.5.4.2 Wire that is submerged during a survey must have adequate insulation for electrical isolation in submersion service.

4.5.4.3 Survey procedures must ensure that the survey wire is electrically isolated from ground and other metallic structures (fences, etc.) traversed during the survey. Care should be taken when crossing metallic structures, such as fences, so that the survey wire does not short to the structure.

4.5.5 AC potentials may become impressed on the survey wire when the wire is extended parallel to AC power lines. Periodic AC potential measurements should be made in such cases to ensure that the AC potential level does not exceed the AC rejection limits of the survey meter.

4.5.5.1 Electromagnetic interference or induction resulting from AC power lines or radio frequency transmitters can induce instrument errors. This condition is often indicated by a fuzzy, fluctuating, or blurred pointer movement on an analog instrument or erratic displays on digital voltmeters.

4.5.6 The type of connection to the pipeline (e.g., test lead, direct contact with aboveground pipe or appurtenances, or probe rod contact) should be documented in the survey header information.

4.6 Data collection

4.6.1 Data collection can be initiated by a time or distance interval, or manually triggered by the surveyor.

4.6.2 Good survey practices, such as those listed in this standard in Section 7 as well as in NACE SP0169[1] and NACE Standard TM0497,[9] must be employed in each type of data collection to avoid measurement errors.

4.6.3 In environments with high contact resistance, a manually triggered system in which measurements are not recorded until the surveyor presses a switch may be used. This can reduce the amount of scatter by allowing sufficient time to place the reference electrodes to achieve good soil contact.

Section 5: Minimizing IR Drop

5.1 Introduction

5.1.1 This section describes requirements and recommendations for minimizing voltage drops other than those at the structure-to-electrolyte interface in potential measurements during CIS.

5.1.2 The measured structure-to-electrolyte potential, at a point, may be influenced by the survey direction because of the voltage drops in the metallic path.

5.1.3 Under some conditions, areas of lower levels of protection can contain higher IR drop errors, making it appear from "on" potentials that the area is more protected, when polarized potentials are actually less negative and the area is less protected.

5.2 IR drop minimization methods

5.2.1 IR drop minimization during CIS may be achieved using a number of different methods:

5.2.1.1 IR drop may not be a significant concern when electrolyte, current densities, depth of burial, and coating condition are consistent, and the magnitude of the IR drop is known or considered to be negligible.

5.2.1.2 The most common method is the instant-off potential method using synchronized current interrupters installed at CP current sources.

5.2.1.3 Another method of IR drop correction for CIS is asynchronous interruption using a waveform analyzer.

5.2.1.4 Other methods include those listed below, but are usually not practical except at discrete locations:

5.2.1.4.1 CP coupons; and

5.2.1.4.2 Step-wise current reduction.

5.2.1.5 IR drop correction methods that correct every measurement provide the most accurate CIS potential data.

5.3 IR Drop Validation methods

5.3.1 Measurements shall be made and recorded to confirm that IR drop correction is valid.

5.3.1.1 For instant-off potential method, waveprints may be used to demonstrate that the interrupters are properly synchronized.

5.3.1.2 Lateral potentials or side-drain potentials may be used to indicate the direction and relative magnitude of current in the electrolyte.

5.3.1.3 Measurement of metallic IR drop may be used to indicate the magnitude and direction of current in the structure (see Appendix A (nonmandatory) for current calculation). Note that this calculation determines the average current for the interval for a single pipeline, and may not be valid for multiple interconnected pipelines, if parallel current paths exist between the FG and NG measurement.

5.4 Instant-off potential method

5.4.1 Comparison of the magnitude of IR drop in potentials measured with the current applied during a CIS can aid in detecting locations of coating faults.

5.4.1.1 The IR drop component in the potential measurement is reduced when in close proximity to the coating fault, thereby reducing the absolute value of the potential.

5.4.1.2 Voltage gradient measurements (such as DCVG or ACVG) are also used to detect coating faults. An increase in magnitude of the voltage gradient with CP current applied is associated with increased current to relatively poorly coated areas.

5.4.2 All components of IR drop result from current in a resistive path. The true polarization of the pipeline can be measured if all currents are instantaneously interrupted. In practice, these conditions are rarely achieved; however, the error can be minimized to obtain sufficiently accurate measurements. Often, there is current that affects the potential measurements that is not the result of the CP system. Sufficient influencing current must be interrupted to measure potentials to the desired accuracy.

5.4.2.1 Foreign pipelines or other cathodically protected facilities that are electrically bonded to the pipeline being surveyed can result in the foreign CP current on the pipeline.

5.4.2.2 Foreign CP systems or other current sources (e.g., DC transit and mine railway systems, high-voltage direct current (HVDC) power transmission, etc.) can cause currents through the electrolyte near the pipeline being surveyed.

5.4.2.3 Long-line currents or telluric currents can cause currents along the pipeline. These currents cannot be interrupted, but can be measured indirectly by methods listed in Sections 7 and 9.

5.4.2.4 The influence of a current source at a given location can be determined by interrupting the source and measuring the change in potential.

5.4.2.5 Other sources of error are listed in NACE Standard TM0497.[9]

5.4.3 Interruption provides a method of reducing or eliminating IR drop by reducing the IR drop caused by CP current sources to zero. Because the polarization is metastable, the remaining potential drop is at the structure-to-electrolyte boundary during the "off" cycle.

5.4.3.1 The advantage of fast-cycle interruption is that an instant-off structure-to-electrolyte potential measurement can be obtained at each measurement location without slowing production, providing more information.

5.4.3.2 A disadvantage of fast-cycle interruption is that this procedure requires a fast voltmeter, precisely synchronized interruption, and data acquisition software that can correctly differentiate between the "on" and instant-off potentials and transitions, and record accurate potentials.

5.4.3.2.1 Because of the difficulty in synchronizing interrupters operating on a very short cycle, slow-cycle current interruption has been historically more common.

5.4.3.2.2 Advances in electronics and GPS have made extremely accurate timekeeping more practical.

5.4.3.3 It is often not practical to use slower cycles to obtain an instant-off potential at each measurement location because of the time required to obtain both an "on" and an instant-off potential measurement.

5.4.3.3.1 The slow-cycle interrupted survey may more easily define locations where the "on" and instant-off potentials have inverted (in these locations, the instant-off potentials are more negative than the "on" potentials, either as a result of uncorrected IR drop, stray current discharge, or possible stray current interference).

5.4.3.3.2 A disadvantage of the slow-cycle interruption is that more depolarization may occur because of the longer "off" cycle during the interruption of the CP.

5.4.3.3.3 Slow-cycle current interruption may or may not differentiate between "on" and instant-off potentials during data collection.

5.4.3.3.3.1 Slow-cycle surveys may identify measured potentials as "on," instant-off, and transitional potentials during data gathering by the data acquisition equipment. When the data are differentiated, separate and continuous plots of "on" and instant-off potentials are usually provided.

5.4.3.3.3.2 Slow-cycle surveys that do not differentiate the potentials during the survey may differentiate the "on" and instant-off potentials by visual interpretation of a graph of the potentials (saw-tooth graphs).

5.4.3.3.3.3. Slow-cycle surveys that do not differentiate the potentials during the survey may also be defined by separate and continuous plots of "on" and instant-off potentials that interpolate between the instant-off potentials. In this case, the graphs shall clearly differentiate between measured and calculated potential measurements.

5.5 Asynchronous interruption method

5.5.1 The advantage of asynchronous interruption is that an IR-corrected structure-to-electrolyte potential measurement can be obtained without synchronized interrupters.

5.5.2 A disadvantage of asynchronous interruption is that the procedure requires a specialized voltmeter and data acquisition software.

5.6 Current interrupters

5.6.1 For interrupted surveys, adequate current interrupters must be installed to interrupt all influencing impressed current CP, including influencing foreign CP current sources, bonds, and galvanic CP. Other sources of current may include foreign pipelines, power company ground neutral bonds, and grounding grids.

5.6.1.1 Types of current sources may include, but are not limited to, constant voltage rectifiers powered by single-phase or three-phase AC, constant-current or constant-potential controlled rectifiers, galvanic anode groundbeds, solar-powered current sources, thermoelectric generators, wind-powered sources, and micro-turbine and engine-generator sources.

5.6.1.2 Rectifiers can be interrupted at the primary AC, secondary AC, or DC side.

5.6.1.2.1 Constant-potential or constant-current controlled rectifiers should be interrupted at the primary AC to prevent spiking. If there is an adjustable maximum voltage limit, the limit may be set to the rectifier output voltage, and the DC output may be interrupted without spiking.

5.6.1.3 Reverse-current switches that are installed for mitigation of stray current shall not be interrupted if, as a result, interference corrosion can occur in a relatively short time.

5.6.1.4 Current interrupters for synchronized surveys must be capable of maintaining synchronous interruption within an acceptable limit for the duration of the survey or resynchronized periodically. For this reason, GPS-synchronized current interrupters should be used for fast-cycle surveys conducted over significant time periods. Current interrupters (pulse generators) for asynchronous surveys must be capable of maintaining the proper interruption cycle within an acceptable limit for the duration of the survey or must be corrected periodically.

5.6.1.5 The output of CP current sources after interrupter installation must be maintained as close as possible to the output prior to installation.

5.6.1.5.1 Maintaining the current output may require increasing the settings to compensate for current reduction, if the reduction is caused by installation of the current interruption equipment.

5.6.1.5.2 Increasing the current output during interruption may also be desired to compensate for depolarization due to interruption. If the purpose of the survey is to determine the level of CP during historical operation, then care must be exercised in adjusting CP levels from normal operating levels.

5.6.1.6 The preferred method for interrupting CP current from foreign sources through bonds is to interrupt the foreign sources that influence the structure being surveyed. There may be cases in which interrupting the foreign sources is impractical, requiring interruption of the bond between the two pipelines. The interruption may require special equipment.

5.6.1.6.1 Bonds that are installed for mitigation of stray current shall not be interrupted or disconnected if, as a result, interference corrosion can occur in a relatively short time, without interrupting the source of the stray current. If interruption or disconnection occurs, interference corrosion can occur in a relatively short time.

5.6.2 Interrupters must be capable of operating at the desired cycle.

5.6.2.1 The duty cycle, or the ratio of the duration CP current is applied ("on" cycle) to the duration the CP is interrupted ("off" cycle), should be adequate to minimize depolarization. Typical duty cycles are 4:1 or 5:1 to allow the structure to repolarize after the "off" cycle. Pipeline coating, current distribution, and environmental conditions should be evaluated to determine the expected rate of depolarization. Higher duty cycles may be desired in areas with rapid depolarization.

5.6.2.2 When spiking extends beyond the duration of the "off" cycle, a longer interruption cycle should be used.

5.6.2.3 Steps should be taken to prevent depolarization by deactivating interrupters when not surveying. This can be done manually or automatically with timers.

5.6.2.4 Steps must be taken to ensure that interrupters using timers are active before the survey resumes.

5.6.3 The interrupters must be checked on a regular basis to ensure that they are operating properly and that there are no problems with the CP current sources.

5.6.3.1 One method is to compare the final potential measurements from the previous day's stopping point to the potentials measured at the same location the next morning. If there is a significant difference, the surveyor shall verify that the interrupters are functioning properly. A typical specification may require verification if the difference is greater than 25 mV.

5.6.3.2 Measurements made to monitor pipeline polarization or depolarization should be documented to aid data interpretation.

5.6.3.3 While it may be impractical to check every interrupter every day, any of the checks above can indicate problems with interrupters. If multiple interrupters are installed, the only way to verify that all the interrupters are operating properly is to test the output of each interrupted current source.

5.6.3.4 The operation of current sources and interrupters should be checked after an electrical storm or a power outage.

5.6.4 Voltage and current output of CP current sources shall be documented.

5.6.4.1 CP current source output settings, current and voltage output before and after interrupter installation, CP current source location and identification (ID), interrupter serial number, and other information should be documented.

5.6.4.2 Structure-to-electrolyte potentials at the nearest test lead may be documented before interrupter installation and immediately before removal to obtain an approximate magnitude of depolarization that has occurred during the survey.

5.6.4.3 Any changes to CP output shall be documented.

5.7 Synchronization Validation Methods

5.7.1 Methods to confirm synchronous operation of the current interrupters and the effective operation of all interrupters at the start of each survey run must be used.

5.7.1.1 Oscilloscopic waveprints may be used to show that the interrupters that influence a location are operating in synchronization.

5.7.1.1.1 Waveprints do not indicate influencing current that is not interrupted. Lateral potentials and measurement of metallic IR drop may be used to obtain an indication of influencing CP current that is not being interrupted or foreign currents that are causing IR drops in the "off" cycle.

5.7.1.1.2 If waveprints indicate interrupters that are not operating in synchronization, an attempt should be made to locate and correct the source of error. If significant errors are observed, the survey may be discontinued until the source of the error can be determined. Previously collected data should be evaluated for acceptable IR drop error. Errors that cannot be corrected shall be noted in the CIS data.

5.7.1.2 Examination of CIS data may also indicate whether current interrupters are out of synchronization, especially for slow-cycle interruption.

5.8 Metallic IR drop

5.8.1 Metallic IR drop should be measured when possible and recorded at the end of each survey run.

5.8.1.1 Direct metal-to-metal measurement of the IR drop and near-ground (NG) vs. far-ground (FG) potentials are acceptable methods.

5.8.1.1.1 The metallic IR drop may be measured directly by connecting one lead of the meter to the near test station and the other to the survey wire attached to the previous test station.

5.8.1.1.2 The metallic IR drop may also be measured by the difference between the NG and FG potentials.

5.8.1.1.3 The two methods are identical when the FG and NG potentials are measured at the same location and in the same manner, changing only the connection to the structure.

5.8.1.1.4 Metallic IR drop should be measured and recorded when applicable for both the "on" and "off" cycles.

5.8.1.2 NG potentials shall be measured and recorded at the start of every survey run, and NG and FG potentials should be measured and recorded at every contact point during the survey run and at the end of the survey run.

5.8.1.3 The amount of current can be calculated when the resistance of the pipeline section is known. See Appendix A (nonmandatory) for methods of calculating the net current based on measured voltage drop and pipeline geometry. Note that this calculation determines the average current for the interval for a single pipeline, and may not be valid for multiple interconnected pipelines if parallel current paths exist between the FG and NG measurement.

5.8.1.4 If the IR drop correction is effective, then theoretically there are no metallic IR drops in the "off" cycle.

5.8.1.5 The magnitude of metallic IR drop represents the net current in the pipeline between the two test points that may be different from the current at specific points within the segment.

5.8.1.6 If the metallic IR drop indicates significant current in the pipe in the "off" cycle, an attempt should be made, when practical, to locate, determine the source of, and interrupt the influencing current. If significant errors are observed, the survey may be discontinued until the source of the error can be determined. Previously collected data should be evaluated for acceptable IR drop error. Errors that cannot be corrected shall be noted in the CIS data.

5.8.1.7 Metallic IR drop for depolarized or native-state surveys should be measured to determine whether all influencing CP has been deactivated.

5.9 Lateral potentials and side-drain potentials

5.9.1 Lateral potentials or side-drain potentials should be measured and recorded at the start of each survey run.

5.9.2 Lateral potentials or side-drain potentials may also be measured and recorded at areas indicating possible problems.

5.9.3 Lateral potentials are "on" and instant-off potentials (when applicable) offset to each side of the pipeline, typically at a distance of approximately two and one-half times the pipe depth.[11]

5.9.3.1 The laterals are designated left or right, with respect to an observer facing downstation.

5.9.4 Lateral potentials are compared with potentials taken directly over the pipeline.

5.9.4.1 If the lateral potential is more negative than the potential directly over the pipeline, it may indicate current in the electrolyte toward the pipeline, assuming consistent coating conditions, current density, and soil conditions. If the lateral potential is more positive than the potential directly over the pipeline, it may indicate current in the electrolyte away from the pipeline, assuming consistent coating conditions, current density, and soil conditions.

5.9.4.2 If local conditions along the pipeline are not consistent, then lateral potentials are affected and do not represent only the current in the electrolyte.

5.9.4.3 Lateral potentials indicating current in the electrolyte toward the pipeline on both sides of the pipeline are usually the result of CP current being picked up by the pipeline. This is normal in the "on" cycle of an interrupted survey. In the "off" cycle, this can indicate influencing current that has not been interrupted.

5.9.4.4 Lateral potentials indicating current in the electrolyte toward the pipeline on one side and away from the pipeline on the other side usually result from current across the pipeline. An example of this is CP current protecting a paralleling pipeline.

5.9.5 Side-drain potentials are the potential differences between two reference electrodes in the "on" and "off" cycles (when applicable), 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.[11]

5.9.5.1 The side-drain potentials are designated left or right with respect to an observer facing downstation.

5.9.6 Side-drain potentials with the reference electrode offset from the pipeline having a potential more positive than the reference electrode located directly over the pipeline may indicate current in the electrolyte toward the pipeline, assuming there are consistent coating condition, current density, and soil conditions. Side-drain potentials with the reference electrode offset from the pipeline having a potential more negative than the reference electrode directly over the pipeline may indicate current in the electrolyte away from the pipeline, assuming there are consistent coating condition, current density, and soil conditions.

5.9.7 If the lateral or side-drain potentials indicate significant current to the pipe in the "off" cycle, an attempt should be made, when practical, to locate, determine the source of, and interrupt the influencing current. If significant errors are observed, the survey may be discontinued until the source of the error can be determined. Previously collected data should be evaluated for acceptable IR drop error. Errors that cannot be corrected shall be noted in the CIS data.

5.9.8 If the lateral or side-drain potentials indicate significant current across the pipe in the "off" cycle, care should be taken to ensure proper pipe location to minimize the IR drop in the soil. An attempt to locate and interrupt the current source producing the current may be desirable.

5.9.9 Lateral potentials or side-drain potentials for depolarized or native-state surveys should be measured to determine whether all influencing CP has been deactivated.

5.10 Electrical connections

5.10.1 Connections should be made at every available contact point in order to minimize voltage drops in the metallic path.

5.10.1.1 If numerous connections are available, then reconnection to a nearby contact point (typically within a distance less than 300 m [1,000 ft]) is not required under normal conditions, if measurements of the metallic IR drop are made and the magnitude of the voltage drop is acceptable.

Section 6: Pipe Location and Marking Procedures

6.1 Introduction

6.1.1 This section describes requirements and recommendations for locating and temporarily marking the position of a pipeline for the purposes of conducting a CIS.

6.2 Pipeline location

6.2.1 Accurate location of a pipeline is required in order to minimize voltage drops in the electrolyte and to obtain the highest resolution of the survey.

6.2.2 Surveyors performing pipe location and marking should review drawings to identify PIs, pipeline crossings, and other features prior to locating the pipeline.

6.2.3 Visual identification of the pipeline by aboveground appurtenances, casing vents, or pipeline markers may not be sufficient to determine the position of the pipeline accurately. Electronic pipeline locators or other devices may be required.

6.2.4 Conductive locating techniques or other more accurate locating techniques and equipment may be required in congested pipeline rights-of-way, areas of deep cover, refuse fill areas, water crossings, small diameter or poorly coated pipe, or areas of high AC potentials.

6.2.5 In the case of a survey performed offshore, magnetic anomaly detectors or other specialized methods may be required for accurate pipeline location.

6.2.6 The accuracy of the locating technique and equipment should be verified at the start of the survey. The accuracy should be confirmed if changes to right-of-way or pipeline conditions affect the accuracy of the technique.

6.2.7 The acceptable reference electrode placement error from the center line of the pipeline depends on the depth of burial of the pipeline, the diameter of the pipeline, and the desired accuracy. A typical specification may allow a deviation of no more than one pipe diameter from the center line of the pipeline. Accurate pipe location is more critical if only "on" surveys are being performed, especially for bare pipelines that have high current density.

6.2.8 Portions of the pipeline found to be improperly located shall be relocated and resurveyed.

6.3 Pipeline marking

6.3.1 A pipeline may be marked directly over the center of the pipeline using flags or other temporary marking material if the survey is not concurrent with the pipeline location.

6.3.2 Pipeline marking may also be used for distance measurement, allowing the surveyor to correct the stationing during the survey to provide accurate stationing between known physical locations.

6.3.3 Marking material must be visible from the previous marker while the survey is conducted.

6.3.4 PIs should be marked so that the surveyor can follow the path of the pipeline.

6.3.5 Allowing marking materials to remain in place may be desirable for the purpose of relocating indications, or conducting additional surveys such as coating evaluation surveys or depolarized surveys.

6.3.6 Certain conditions such as areas with crops being harvested, areas with livestock, well-traveled areas, etc., may require immediate removal of the marking materials and survey wire. Caution should be exercised when using semipermanent marking materials, such as paint.

6.3.7 Areas found to have unacceptable distance errors shall be relocated and resurveyed.

6.4 Pipeline distance measurement

6.4.1 Pipeline distance measurement must be sufficiently accurate to relate the potential data with the proper location on the pipeline, to allow precise relocation of any indications found, and to allow integration of CIS data with other data sets. A typical specification may allow a distance error of ±10 m per km (50 ft per mi), but may be more stringent, especially if integration with other data sets is required or anticipated in the future.

6.4.1.1 A sufficient number of points must be identified and recorded together with the CIS potential data, typically every 30 m (100 ft), and updated at every test lead or contact point and other key physical features with station numbers provided.

6.4.1.2 On land, stationing for markers can be performed by using a surveyor's tape or chain, a surveyor's wheel, other traditional land surveying methods, GPS or DGPS receiving equipment, or by using a wire counter. Distance measurement should be correlated with existing stationing, when available, to ensure accuracy.

6.4.1.3 Stationing may be automatically entered into the data stream using a wire counter, GPS or DGPS receiving equipment, or other distance measurements. The surveyor shall ensure that the method used for distance measurement meets the required accuracy.

6.4.1.4 When the wire counter method is used for distance measurement, appropriate measures shall be taken to ensure that the distance measured by the spooling wire corresponds with distance traveled along the pipeline. These measures include staking the wire with nonmetallic materials at bends in the pipe, fences, or elevation changes, and ensuring the wire counter is not incrementing when not surveying or slipping when surveying.

6.5 Other considerations

6.5.1 GPS or DGPS coordinates, aboveground marker (AGM) sites, geo-referencing information, or other data may be desired in conjunction with the survey. This information is particularly important to aid in integrating multiple data sets, such as when performing ECDA.

Section 7: CIS Procedures

7.1 Introduction

7.1.1 This section describes requirements and recommendations for performing CIS.

7.2 Survey interval

7.2.1 The required survey interval for a continuous evaluation of the structure depends only on the depth of burial for bare pipelines. For coated pipelines, the relationship is more complex, and is a function of the depth of burial and the ratio of the resistivity of the coating to the resistivity of the electrolyte. Under normal conditions, the relationship used for bare pipeline is conservative. The maximum survey interval shall be less than three and a half times the depth of cover of the pipeline in order to obtain a continuous evaluation of the structure, without gaps.[12]

7.2.2 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.

7.2.3 Pipelines with a diameter much greater than the depth of burial or partially buried pipelines may require more than one survey pass offset from the center line of the pipeline in order to perform a detailed assessment. For pipeline corridors with closely spaced electrically continuous pipelines, a single survey may be sufficient to represent all the structures.

7.3 Reference electrode placement

7.3.1 Valid structure-to-electrolyte potential measurements require proper reference electrode placement and contact with the electrolyte.

7.3.2 Structure-to-electrolyte potentials shall not be taken through frozen ground, asphalt, or concrete, unless additional measurements and inspections can be made to demonstrate that potentials measured through pavement are representative of the level of protection directly below the reference electrode.

7.3.2.1 Because the electrical resistance through cracks in pavement is much lower than the resistance through the pavement, potential measurements may not be representative of the pipeline directly below the reference electrode. Potential measurements for the purpose of CIS shall be made by drilling through the pavement, made offset to the pavement, where possible, and noted as such (see Paragraph 7.3.5.3), or noted on the survey as being made over pavement. For potentials made over pavement, additional methods of reducing contact resistance include flooding the pavement with water and using large surface area reference electrodes. Additional measurements and inspections to confirm the effectiveness of these methods include comparing potentials measured through pavement with potentials measured with holes drilled in the pavement.

7.3.2.2 The benefits of obtaining these data and the accuracy of the methods used must be weighed against the cost to obtain the data in areas in which the pipeline is buried beneath asphalt or concrete.

7.3.2.3 Holes drilled through pavement for the purposes of potential measurements should be proved in order to confirm that all layers of the pavement have been penetrated, such as using a probe rod to ensure that the hole extends into the soil.

7.3.3 Potential measurements shall not be taken in areas where the pipeline is above-grade, cased, or otherwise not in contact with the electrolyte. The appropriate skip distance shall be recorded along with a comment describing the feature. The survey shall resume where the pipeline contacts the electrolyte.

7.3.4 Surveys containing excessive contact resistance that influences structure-to-electrolyte potential (scatter) shall be resurveyed unless adequate valid data are discernible.

7.3.4.1 The biggest impediment to accurate CIS structure-to-electrolyte potentials is contact resistance caused by hard or dry soil, vegetation, rocks, or other obstacles to good electrical contact between the reference electrode and the soil. Surveys should be scheduled when contact resistance is expected to be acceptable or provisions for watering or other measures may be necessary.

7.3.4.2 While a survey with no scatter is impossible in many conditions, the structure-to-electrolyte potentials must be discernable throughout the survey.

7.3.4.3 A number of conditions can cause scatter:

(a) Rocky conditions;

(b) Heavy brush or dry vegetation;

(c) Dry soil or sand; and

(d) Surveyor error.

7.3.4.4 High-input resistance voltmeters tend to float when measuring an open circuit. If good contact with the soil is not made, spurious data may be taken. The surveyor must be watchful for open circuits or scatter caused by high contact resistance, broken survey wire, or disconnected or high-resistance connections. Invalid data shall be deleted or noted when observed, and the areas must be resurveyed.

7.3.4.5 Significant distances without valid potentials, or with potentials that cannot be interpreted due to scatter, must be resurveyed continuously from the nearest metallic connection.

7.3.4.6 Dry soil, rocky conditions, excessive vegetation, and other conditions may require watering, digging, or cutting vegetation to obtain valid structure-to-electrolyte potentials. High contact resistance can often be minimized or eliminated by proper survey techniques:

7.3.4.6.1 Adjusting the input resistance of the meter to the appropriate level when possible;

7.3.4.6.2 Allowing sufficient time for the reference electrodes to make good contact;

7.3.4.6.3 Placing the reference electrodes properly;

7.3.4.6.4 Using pointed reference electrode plugs to penetrate the dry crust of the soil;

7.3.4.6.5 Using plugs that are more porous or plugs with larger surface area; and

7.3.4.6.6 Applying water to the soil where the reference electrode makes contact.

7.3.5 Conditions on pipeline rights-of-way may make measurements directly over the pipeline impractical. In such cases, potentials may be measured offset to the center line of the pipeline.

7.3.5.1 The surveyor shall ensure there are no intervening structures when offset measurements are obtained.

7.3.5.2 The instant-off potentials are representative of the level of protection of the structure; however, resolution is reduced, comparable to increasing the depth of cover.

7.3.5.3 A comment in the data shall be made noting the point at which the potentials begin to be offset from the center line of the pipeline, and the distance the measurement(s) were offset from the pipe's center line. The direction of offset (left or right, with respect to an observer facing downstation) and the reason for this action shall be noted.

7.3.5.4 A comment in the data shall be made noting when the potential measurements are no longer offset.

7.4 Areas surveyed

7.4.1 If the goal of a CIS is to evaluate the level of protection of a segment of pipeline, the entire length of the segment should be surveyed.

7.4.2 For areas difficult to survey due to obstructions, such as lakes and waterways, large distances covered by asphalt or concrete, or residential areas, potential measurements in these obstructed areas are necessary. Potentials measured offset to the pipeline may be less costly but have reduced resolution. The benefits of obtaining these data and the accuracy of the methods used must be weighed against the cost to obtain the data.

7.4.3 The level of protection from the adjacent potentials may be considered when the obstruction is short relative to the pipeline depth, and the potentials on either side of the obstruction indicate consistent levels of protection.

7.4.4 Holes should be drilled through the pavement to obtain potential measurements when the obstruction is longer and the level of protection from the adjacent potentials cannot be determined. The appropriate interval for the holes is determined using the methods in Paragraph 7.2.

7.5 Survey direction

7.5.1 CIS may be performed in either the upstation or downstation direction. The data shall clearly indicate which direction the survey was conducted.

7.5.2 Metallic IR drop error in the "on" cycle accumulates as the survey run progresses, and adds to or subtracts from the magnitude of the potentials, depending on the survey direction. If the measurements contain sufficient metallic IR drop error, the error may decrease the magnitude of the "on" potentials below that of the instant-off potentials. This may cause problems in differentiating between the "on" and instant-off potentials, and may be corrected by conducting the survey run in the opposite direction.

This does not remove the IR error, but will change the effect of the metallic IR drop.

7.5.3 Survey runs that are reruns or will be compared to previous CIS data should be run in the same direction as the original CIS.

7.6 Start and end of survey run

7.6.1 Survey runs should be conducted from one metallic connection to the next in order to obtain metallic IR drop measurements.

7.6.2 When contact points are not available at the end of the survey run, metallic IR drop measurements from adjacent survey runs should be evaluated to ensure that the measurements did not include significant metallic IR drop error.

7.6.3 Outside forces may cause the survey wire to break during a CIS, and it may not be practical to attempt to find the break and repair it. In these cases, the location of the end of the survey shall be clearly marked, and a station number calculated based on the distance surveyed. A survey back to that point from the next metallic connection shall be conducted, and the ending stations of the two surveys should match.

7.6.4 If significant metallic IR drop is a concern, it may be necessary to resurvey the entire section following a broken wire in order to obtain the metallic IR drop measurements.

7.7 Meter scale

7.7.1 The surveyor shall select the lowest practicable range on the survey meter or use an auto-range mode when possible for more accurate measurements.

7.8 Close-interval survey data

7.8.1 Typical header information may include:

(a) Pipeline operator and location name;

(b) Line identification and size;

(c) Starting KP/MP/station number;

(d) Technician identification;

(e) Voltmeter/data logger serial number and identification;

(f) Type of connection (see Paragraph 4.5.6) and meter polarity (see Paragraph 4.3.3);

(g) AC structure-to-electrolyte potential;

(h) NG structure-to-electrolyte potential (if an interrupted survey, “on” and instant-off potentials);

(i) Left and right lateral structure-to-electrolyte or side-drain potentials (“on” and instant-off potentials, if an interrupted survey);

(j) Type of reference electrode used (required if other than CSE);

(k) Ambient temperature (for reference electrode temperature compensation);

(l) Survey direction;

(m) Survey interval;

(n) Waveprint (if an interrupted survey);

(o) Date and time; and

(p) Description of survey conditions.

7.8.2 Typical footer information may include:

(a) Ending KP/MP/station number;

(b) Reason for ending survey run (new connection available, broken wire, end of limits of survey);

(c) FG structure-to-electrolyte potential (“on” and instant-off potentials, if an interrupted survey);

(d) NG structure-to-electrolyte potential (“on” and instant-off potentials, if an interrupted survey);

(e) Calculated or measured metal IR drop (“on” and instant-off, if an interrupted survey);

(f) Waveprint (if an interrupted survey); and

(g) Time.

7.8.3 Typical additional measurements during the survey may include:

(a) “On” and instant-off (if an interrupted survey) NG casing-to-soil potentials at casing vents;

(b) “On” and instant-off (if an interrupted survey) FG structure-to-electrolyte potentials at each metallic foreign line crossing;

(c) “On” and instant-off (if an interrupted survey) NG foreign structure-to-electrolyte potentials at each metallic foreign line crossing;

(d) “On” and instant-off (if an interrupted survey) FG and NG structure-to-electrolyte potentials at each contact point that is passed without reconnection;

(e) Bond current and polarity (for both the “on” and “off” cycles, if an interrupted survey) at each bond location;

(f) Line current test spans (for both the "on" and "off" cycles, if an interrupted survey);

(g) Potentials on each side of isolating devices; and

(h) Location and output of CP current sources.

(i) Additional measurements should be taken at low potential indications and when structure-to-electrolyte potentials change abruptly (see Paragraph 7.8.5).

7.8.4 Sufficient field comments shall be entered while conducting the survey to document any physical features that may significantly affect the measurements or aid in the relocation of indications for additional testing or for remediation.

7.8.4.1 Comments describing survey conditions and features that affect the potential measurements such as surface conditions (vegetation, soil conditions, land usage, moisture content, etc.), casings, line crossings, bonds, rectifiers and galvanic groundbeds, and power line crossings shall be included. It is important to document changes in surface conditions in order to explain any changes in the potential profiles.

7.8.4.2 Comments at each geographical feature such as pipeline appurtenances, line markers, physical features such as hills, creeks, ditches, and fences, and street and highway names, sufficient to facilitate relocation of anomalies shall be recorded.

7.8.5 Additional measurements should be taken at low-potential sites and when structure-to-electrolyte potentials change abruptly:

7.8.5.1 The surveyor should verify meter connections and continuity of survey wire.

7.8.5.2 The surveyor should measure lateral potentials or side-drain potentials.

7.8.5.3 The surveyor should obtain waveprints if conducting an interrupted survey.

7.8.5.4 The surveyor should measure the AC structure-to-electrolyte potential to ensure the manufacturer's criteria for maximum AC rejection are not exceeded.

7.8.5.5 The surveyor should check the reference electrodes when the data appear to be affected.

7.8.5.6 The surveyor may resurvey a portion of the pipeline to verify that the data are repeatable.

7.8.5.7 The surveyor should make stationary potential measurements to ensure that the data are time-independent.

7.8.5.8 The surveyor should ensure good contact between the reference electrode and the electrolyte by comparing potential measurements at normal survey pace and stationary.

7.8.5.9 The surveyor may ensure good contact between the reference electrode and the electrolyte by comparing structure-to-electrolyte potentials at the ground surface and with water applied.

7.8.5.10 The surveyor may decrease the survey interval in order to provide higher resolution.

7.8.6 Invalid potential measurements obtained shall be deleted or noted as such and resurveyed with the problem corrected.

7.8.7 The surveyor shall record the results of all tests performed, in accordance with Paragraph 7.8.6.

7.9 Conditions observed during surveys

7.9.1 During the survey, surveyors shall notify the appropriate person of any indication that may be characteristic of immediate safety issues, integrity concerns, or other issues including:

(a) Stray current interference indications;

(b) Indications of impressed current CP connected with improper polarity;

(c) Excessive potentials on amphoteric pipeline materials;

(d) Failures of CP current sources;

(e) Excessive AC potentials;

(f) Indications of leaks or other conditions that the operator may have specified;

(g) Any conditions observed that could make data from a CIS difficult to interpret properly, or make the survey impractical to perform, such as those listed in Paragraph 1.4; and

(h) Any conditions that the operator has identified as immediate indications. These include indications that the pipeline operator considers as likely to have ongoing corrosion activity and that, when coupled with prior corrosion, pose an immediate threat to the pipeline under normal operating conditions.

7.10 Reference electrodes

7.10.1 Surveyors shall examine the reference electrodes on a regular basis and calibrate the cells against a known standard (see Paragraph 4.4.3).

7.10.1.1 If two reference electrodes are being used, they shall be compared at the start of each survey run and at any time during the survey in which the potentials appear to differ between the reference electrodes. The two reference electrodes must match within an acceptable degree of error, typically a maximum variation of ±5 mV.

7.10.1.2 A CSE must contain adequate amounts of saturated solution and excess copper sulfate crystals.

7.10.1.3 Plugs shall be examined for damage and replaced when excessively worn or cracked. New plugs should be soaked in distilled water overnight.

7.10.1.4 Plugs shall be examined for contamination and cleaned or replaced when contaminated with salts, oils, chemicals, etc.

7.10.1.5 Any reference electrodes that do not meet these requirements shall be rebuilt and recalibrated, or replaced.

7.10.1.6 Potential measurements obtained with reference electrodes that do not meet these requirements shall be deleted or noted as such, and resurveyed with the problem corrected. Previously collected data should be evaluated for acceptable accuracy.

7.11 Ending the survey run

7.11.1 When another test point is encountered, the appropriate measurements shall be made to complete the survey run (see Paragraph 7.8.2), break the trailing wire, and make an electrical connection to the new contact point.

7.12 Data

7.12.1 When practical, the surveyor should periodically upload the CIS data when the memory in the data logger is volatile to ensure that data are not lost.

Section 8: Hybrid CIS Procedures

8.1 Introduction

8.1.1 This section describes requirements and recommendations for performing hybrid CIS.

8.2 Types of hybrid CIS

8.2.1 Hybrid CIS are close-interval surveys made with additional measurements to enhance the interpretation of the data.

8.2.2 Types of additional measurements include:

(a) surface potential gradients perpendicular to the pipeline (called CIS with side-drains or intensive measurement surveys);

(b) surface potential gradients along the pipeline (also called trailing wire DCVG surveys); and

(c) lateral potentials (called CIS with lateral potentials).

8.3 Requirements for hybrid CIS

8.3.1 The CIS component of hybrid survey techniques must meet the requirements of this standard.

8.3.2 In order to be considered a CIS technique, the additional measurements should be made at the same intervals as the CIS potential measurements, e.g., a CIS with side-drains must include potentials measured directly over the pipeline and side-drain potential measurements at this same interval. A survey with additional measurements that does not meet this requirement should be called a CIS with additional measurements rather than a hybrid CIS.

8.3.3 For valid interpretation of the data, hybrid surveys with lateral potentials or side-drain potentials should be performed by measuring the lateral potentials or side drains to both sides of the pipeline. Lateral potentials or side drains measured to only one side of the pipeline may misinterpret earth currents across the pipeline as cathodic or anodic locations. A survey with additional measurements that does not meet this requirement should be called a CIS with additional measurements rather than a hybrid CIS.

8.3.4 For the additional measurements to be performed in the same conditions as the CIS, hybrid surveys must have the additional measurements performed at the same time and at the same locations along the pipeline as the CIS measurements. For example, the data from a CIS and a series of lateral potential measurements performed at different times cannot be combined and called a CIS with laterals. A survey with additional measurements that does not meet this requirement should be called a CIS with additional measurements rather than a hybrid CIS.

8.3.5 Hybrid surveys may be performed using the techniques described in Section 5 for minimizing IR drop. When performing the CIS according to these techniques, the additional measurements may be corrected for IR drop, made without correcting for IR drop, or both measurements may be included. For example, when performing an interrupted CIS with side drains, the CIS should record both "on" and instant-off potentials, but the side drain potentials may be performed during the "on" cycle, during the "off" cycle, or both, depending on the objectives of the survey.

8.3.5.1 "On" surface potential measurements are representative of conditions when CP is applied.

8.3.5.2 "Off" surface potential measurements are representative of currents in the electrolyte or along the pipeline other than those of the CP being interrupted, such as uninterrupted CP sources, long-line corrosion currents, or stray current.

8.4 Interpretation of survey data

8.4.1 This standard does not address interpretation of survey data. Survey data shall be reviewed and interpreted only by persons qualified as described in Paragraph 1.3.1 and experienced in these types of data.

Section 9: Offshore CIS Procedures

9.1 Introduction

9.1.1 This section describes requirements and recommendations for performing CIS on submerged pipelines.

9.1.2 This section includes procedures for various methods for performing CIS on submerged and offshore pipelines. It is not the intent of this section to preclude the use of other survey techniques such as trailing wire/towed fish (unmanned towed submersible) method.

9.1.3 Additional safety considerations and safety equipment may be required for offshore surveys.

9.2 CIS of conventional vertical riser (drop-cell survey)

9.2.1 Good metal-to-metal contact with the pipeline should be made at the location of electrical connection (e.g., at the offshore riser). It may be necessary to use a probe designed for the task. Probing through thick rust should not be attempted.

9.2.2 The isolation flange in the pipeline riser (if any) should be located and potential measurements on both sides of the isolating flange recorded with the reference electrode in a stationary position.

9.2.3 Measurements should be performed from the lowest accessible level of the platform to minimize drift of the reference electrode.

9.2.4 The reference electrode should be lowered to the desired depth of the first measurement while maintaining electrical contact with the pipeline side of the isolation flange (if any), and a structure-to-electrolyte potential measurement should be recorded.

9.2.4.1 The reference electrode should be raised by the survey interval, and the potential should be recorded. Positive shifts that may indicate coating damage should be observed and documented as the reference electrode is raised to the surface. The process should be continued until the reference electrode is at the surface, and the potential at the surface should be recorded.

9.2.4.2 Care should be taken to avoid hitting the drop-cell on any submerged structures, and the cable should not be allowed to rub against barnacles.

9.2.4.3 When water currents cause the reference electrode to drift away from the riser, an error is introduced in the potential measurements. This can be avoided by running the electrode down a guy wire if available, or by using a weight on the cable. The reference electrode shall be electrically isolated from any metallic weight or guy wire.

9.2.5 The potential measurement at the surface should be compared with the potential obtained at the start of the survey to ensure that the reference electrode has not been contaminated or the wire insulation has not been damaged.

9.2.6 Some possible errors that can occur during a drop-cell survey include:

9.2.6.1 Side motion of the reference electrode from seawater currents. The electrode must drop vertically, and if not dropped vertically, the angle should be documented. If the reference electrode is carried too far by the current, the drop shall be repositioned.

9.2.6.2 If a CSE is used in a high chloride environment, the stability (lack of contamination) of the CSE must be determined before the data may be considered valid.[8]

9.2.6.3 If potentials become erratic, the cable insulation may have been damaged, exposing the copper wire to seawater. The reference electrode should be removed from the cable, and the cable should be repaired or replaced.

9.3 CIS of pipelines in shallow water

9.3.1 Shallow water offshore surveys (too shallow for remotely operated vehicle assisted [ROV assisted] surveys as described in Paragraph 9.4.3) should use the trailing-wire/weighted-electrode survey method or other appropriate survey method.

9.3.2 A low-resistance (metal-to-metal) electrical connection to the pipeline should be established with a clip-on connector or clamp that is mechanically sound.

9.3.3 A weighted reference electrode should be towed along the bottom above the pipeline while the connection to the pipeline is maintained by spooling out a light gauge insulated wire from a survey vessel. See Section 4 for requirements for reference electrodes and wire for submerged service.

9.3.4 The structure-to-electrolyte potential shall be measured and recorded along with distance onboard at appropriate intervals. See Section 7 for requirements for survey interval.

9.3.5 The pipeline may be located using a variety of methods:

9.3.5.1 Visual location, where practical;

9.3.5.2 Electronic positioning in conjunction with the pipeline's as-built coordinates; and

9.3.5.3 Magnetometer pipe location using buoys at an offset to mark the pipeline.

9.4 CIS of pipelines in deep water

9.4.1 Deep water offshore surveys should be performed using an ROV connected to a survey vessel through an umbilical. The survey procedure should be capable of recording both structure-to-electrolyte and electric field gradient (EFG) potential values. When an ROV is not available, other appropriate survey methods are available.

9.4.2 Two methods that may be used are trailing-wire or remote-electrode methods. The choice is dependent on water depth, proximity to platforms, and pipeline burial.

9.4.3 ROV assisted trailing-wire method

9.4.3.1 The ROV assisted trailing-wire method should be used adjacent to platforms (within 150 m [500 ft]) in less than 30 m (100 ft) water depths in which the ROV remote-electrode method should not be used, and on buried pipelines.

9.4.3.2 The survey should be performed by first establishing a direct electrical connection to the pipeline at a riser. Two Ag/AgCl reference electrodes mounted on an ROV should be carried above the pipeline while the connection to the pipeline is maintained by spooling out a light gauge insulated wire from a wire supply apparatus aboard the survey support vessel. The structure-to-electrolyte and EFG potentials should be continuously measured and recorded onboard using a microcomputer linked to an electronic data logger.

9.4.3.3 The two Ag/AgCl reference electrodes should be mounted on the ROV and arranged so that one electrode is located approximately 150 to 300 mm (6 to 12 in.) above the pipeline, while the second electrode is mounted approximately 610 mm (24 in.) vertically above the first electrode. Electrode configuration may vary somewhat, depending on the pipeline accessibility, pipeline diameter, and operating conditions.

9.4.3.4 Two types of potential measurements should be continuously recorded onboard the surface vessel. The structure-to-electrolyte potential should be measured using the Ag/AgCl electrode placed closest to the pipeline. The EFG should be measured by recording the potential between the two ROV mounted electrodes.

9.4.3.5 Both measurements should be recorded onboard using a computerized data acquisition system that is programmed to record structure-to-electrolyte potential and EFG at a rate such that at the speed of the survey, potentials are recorded at appropriate intervals. Both potential measurements should be displayed on a video monitor, stored, and printed. A calibration stab (temporary electrical connection to the pipeline) should be made (typically at anodes) at approximately 460-m (1,500-ft) intervals during the course of a survey run. Surveyors may consider using a water jet to expose the pipe for a calibration stab when the line is buried.

9.4.3.6 Downline position on the pipeline should be determined by use of acoustic positioning and conventional surface positioning equipment electronically linked to provide a continual update of the true vehicle position relative to the pipeline. During the survey, position fixes should be recorded at approximately 100-m (300-ft) intervals. A marker should be simultaneously noted in the CIS data to provide references for computation of survey stationing and the subsequent generation of plots showing potential vs. pipeline station number.

9.4.3.7 The procedure should be modified when a survey is started at a location on the pipeline not readily accessible to a riser or an onshore test connection point. Rather than making a direct electrical connection to the pipeline, the light gauge wire should be attached to a weighted calibrated Ag/AgCl reference electrode that is lowered to the sea floor near the pipeline. The location of the electrode is not critical because it serves simply as a fixed voltage source. After the electrode is lowered to the sea floor, the ROV equipped with a metallic contact probe and two reference electrodes should record a potential measurement at the closest accessible test location, which is typically an anode bracelet. The potential should be recorded between the pipeline (through the metallic contact probe) and the stationary electrode attached to the disposable wire. This potential value should be entered into the data acquisition system as an offset potential. The survey should then proceed by continuously measuring the electrodes mounted on the ROV closest to the pipeline as the ROV travels along the pipeline. The pipeline potential at any point along the pipeline is the potential between the stationary electrode and the ROV-mounted electrode, added to the initial offset voltage.

9.4.4 ROV assisted remote-electrode method

9.4.4.1 The ROV assisted remote-electrode method may only be used on unburied or partially buried pipeline in water depths in excess of 30 m (100 ft), and not where the pipeline is adjacent to the platform structure.

9.4.4.2 The survey should be conducted using a remote Ag/AgCl electrode as a stable voltage source instead of a connection to the riser or as a stationary electrode. An electrode is defined as remote when the distance between the electrode and the structure being surveyed (pipeline) is such that a change of electrode position does not change the measured potential between the electrode and the structure. On a typical coated subsea pipeline cathodically protected by sacrificial bracelet anodes, an electrode is considered remote at a distance of 30 m (100 ft) or more.

9.4.4.3 The remote electrode is typically mounted on the ROV umbilical approximately 6 m (20 ft) below the survey vessel's hull. At the start of a remote electrode survey, a direct contact structure-to-electrolyte potential should be measured between the remote electrode and the pipe using a metallic contact probe aboard the ROV. This establishes the fixed voltage offset between the pipe and the remote electrode that is entered into the data acquisition system. The survey should then proceed by continuously measuring the potential between the remote electrode and an electrode mounted on the ROV. Direct contact potential measurements should be taken at approximately 1,600-m (1-mi) intervals to recalibrate the remote electrode and adjust the offset voltage accordingly.

9.4.4.4 Data acquisition, measurement of EFG, and positioning are as described above for the ROV assisted trailing-wire survey.

Section 10: Dynamic Stray Current Considerations

10.1 Introduction

10.1.1 This section describes requirements and recommendations for conducting CIS in areas subject to dynamic stray currents (i.e., currents from electric transit systems, telluric currents, etc.) and provides methods to correct for voltage drops other than those across the structure-to-electrolyte boundary produced by these currents.

10.1.2 This section does not address procedures for static stray-current influence.

10.1.3 CIS influenced by dynamic stray currents contain voltage drops other than those across the structure-to-electrolyte boundary, with the stray currents representing a varying source of error.

10.1.4 Assessment of the protection level in areas subject to dynamic stray or telluric currents shall be done either by performing the survey when no stray current activity is occurring, or applying methods such as those in NACE SP0169.[2]

10.1.5 Pipelines subjected to high-frequency dynamic stray current may require correction methods outside the scope of this section.

10.2 Identification of dynamic stray current

10.2.1 Dynamic stray current can be identified by recording the structure-to-electrolyte potentials over a time period, typically 24 hours. If deviations in the structure-to-electrolyte potentials are significant (typically greater than 30 mV), stray current correction of the survey results is warranted.

10.2.2 Dynamic stray currents generated by electric transit systems can be characterized by minor variations during low traffic hours, as shown in Figure 1.

10.2.3 Telluric currents are currents in the earth that result from geomagnetic fluctuations, principally from sunspot activity. This electrical disturbance is observed on pipelines and other affected structures as random current and potential fluctuations, as shown in Figure 2.

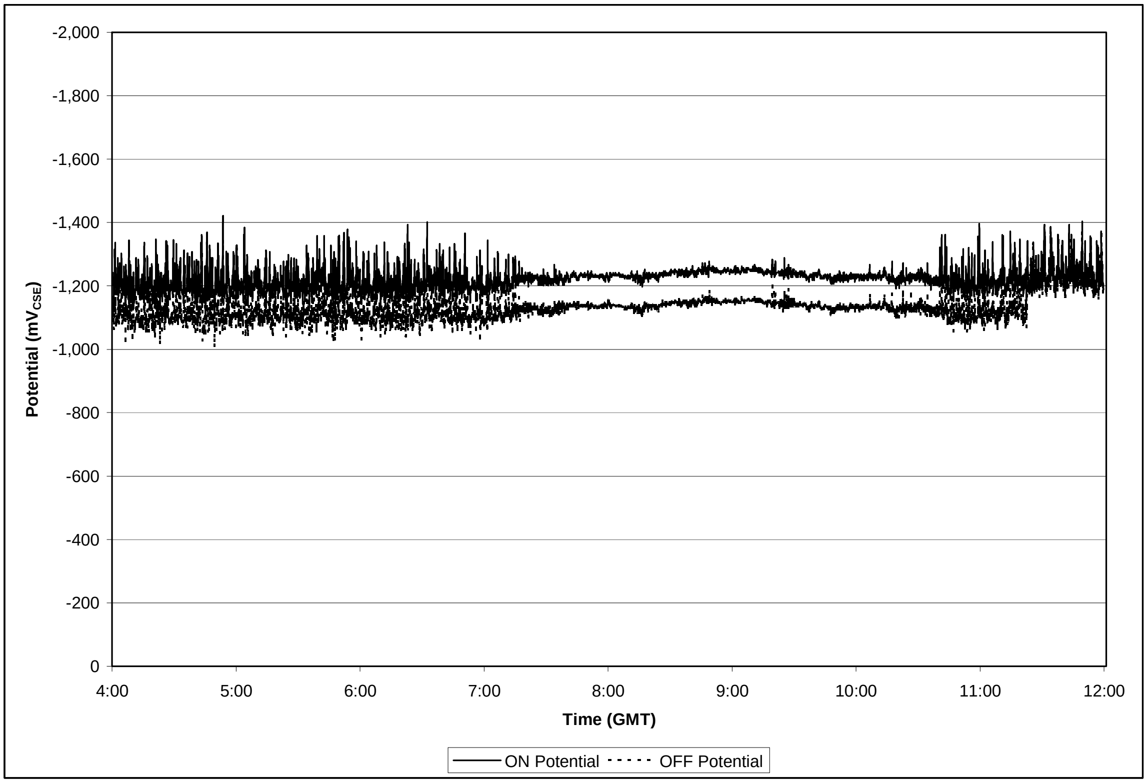

FIGURE 1: Dynamic Stray Current as a Result of Electric Transit System

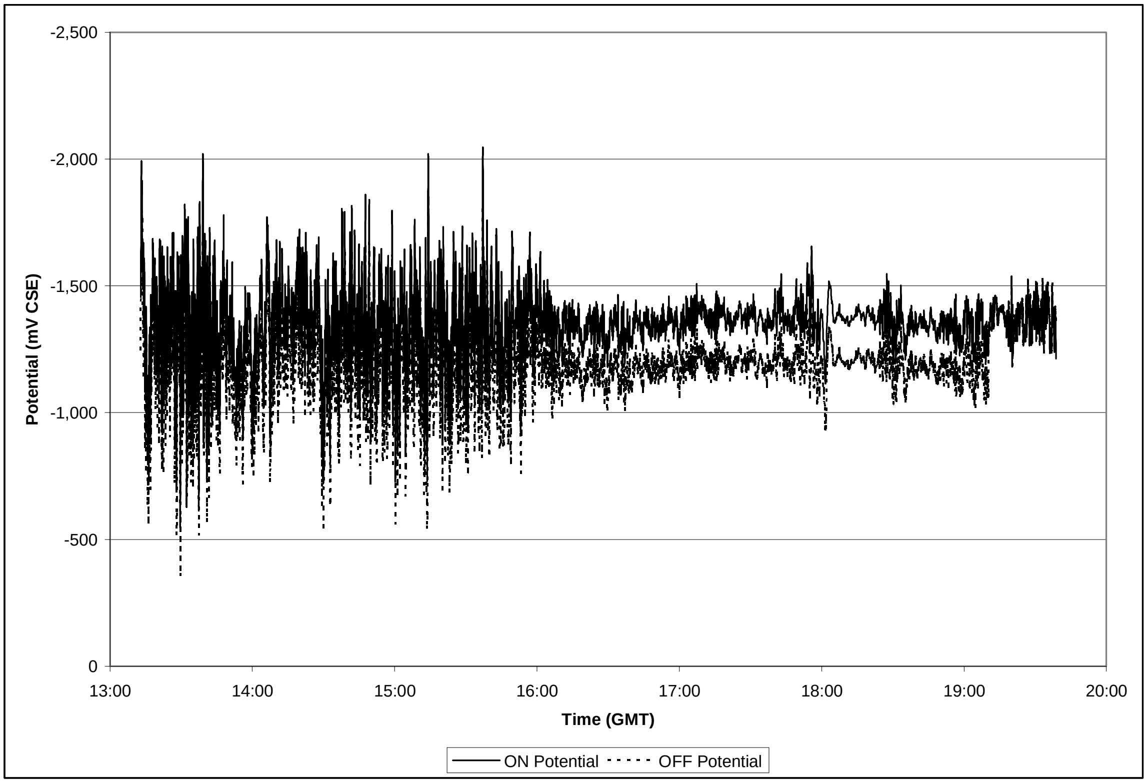

FIGURE 2: Dynamic Stray Current as a Result of Telluric Currents

10.2.4 The intensity of the effect on an underground structure is related to its geometry, coating integrity, latitude, and sunspot activity; thus there can be periods with little or no telluric activity on underground structures. At other times, the effect on structure-to-electrolyte potentials can be significant.

10.2.5 Long-term data recordings of the structure-to-electrolyte potential at numerous locations are required to ascertain the influence of telluric currents on structure-to-electrolyte potential measurements.

10.2.6 Telluric current is often observed on pipelines with little or no influence on the structure-to-electrolyte potential at the observed location.

10.2.7 Telluric current effects on the structure-to-electrolyte potential are most significant at changes in direction of the pipeline or at electrical discontinuities, such as dielectric isolation devices.

10.3 Stray and telluric current compensation

10.3.1 One method of dynamic stray-current compensation is to correct the CIS potentials with the variation caused by dynamic stray current as recorded by stationary data logger(s). For the compensation to be effective, the structure-to-electrolyte potentials recorded in the CIS must be precisely synchronized with the stationary recorded potentials, such as by use of the same time standard (e.g., Coordinated Universal Time [UTC] as provided by GPS). Frequencies associated with telluric currents and many types of dynamic stray current are generally low, typically less than 1 Hz. The precision required for correction of dynamic stray currents with significantly higher frequencies may be impractical to achieve.

10.3.2 The number and location of the static recorders required to effectively compensate for stray-current measurement error on the section of pipeline to be surveyed shall be determined by a qualified person such as described in Paragraph 1.3.1 and experienced in CIS and dynamic stray-current compensation.

10.3.3 In areas of telluric current activity, stationary data loggers are typically connected to the pipeline at intervals not exceeding 5 km (3.1 mi).

10.3.4 In areas of dynamic stray currents from DC traction systems, data loggers are typically connected to the pipeline at intervals not exceeding 2 km (1.2 mi).

10.4 Calculating the compensation value

10.4.1 Structure-to-electrolyte potentials compensated for dynamic stray current shall be clearly designated as such.

10.4.2 Methods for compensating structure-to-electrolyte potentials for measured variations as a result of dynamic stray current shall be determined by a qualified person such as described in Paragraph 1.3.1 and experienced in CIS and dynamic stray-current compensation.

10.4.3 Methods for compensating structure-to-electrolyte potentials for measured variations as a result of dynamic stray current shall be documented and included with the CIS data.

Section 11: DC Cell-to-Cell Surface Potential Gradient Surveys

11.1 Introduction

11.1.1 This section addresses DC cell-to-cell surface potential gradient surveys used to evaluate the direction of CP or corrosion current in the soil. Cell-to-cell surveys (such as traditional DCVG) used to evaluate the effectiveness of the coating are described in other NACE publications. 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.

11.1.2 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. Both techniques can be performed as a stand-alone survey or can be combined with CIS as a hybrid survey. This section addresses stand-alone surface potential gradient surveys. Hybrid surveys are addressed in Section 8 of this standard.

11.1.3 A hot-spot survey 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 copper-copper sulfate [CSE]) in contact with the earth. This type of survey can be used to locate suspected anodic conditions on the pipe.

11.1.4 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 copper-copper sulfate [CSE]) in contact with the earth, one directly over the pipeline, and the other offset to each side of the pipeline. This type of survey can be used to locate suspected anodic conditions on the pipe and to evaluate a net protective current to the pipeline to identify long-line corrosion activity.

11.1.5 If the pipeline has a CP system, these surveys may be performed with CP applied in order to evaluate the effectiveness of the CP system or, where practical, may be performed with the CP system de-energized and sufficient time allowed for the structure to depolarize to native conditions, in order to evaluate corrosive behavior prior to installation of the CP system or during intermittent application of CP.

11.2 Pre-Job Considerations

11.2.1 Pre-job considerations are similar to those listed in Section 3.

11.3 Instrumentation and Equipment

11.3.1 Instrumentation and equipment are similar to those listed in Section 4. Surface potential gradient surveys do not require electrical connection to the pipeline, therefore Paragraphs 4.3 and 4.5 do not apply.

11.3.2 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 may require a more stringent criterion for balancing than for close-interval surveys. Electrical circuits to adjust the potential difference between the reference electrodes for more accurate balancing may be used.

11.3.3 The voltmeter should have a sufficiently small scale (typically 100-mV full scale or smaller) to make accurate surface potential gradient measurements. Because the surface potential gradient values to be measured can be expected to be much lower than for structure-to-electrolyte potentials, the meter may require a more stringent criterion for accuracy than for close-interval surveys.

11.3.4 Meters can be connected in either polarity, or the cells may be alternated (leapfrogging), but data shall clearly indicate the polarity of the potentials by some convention and clearly identify polarity reversals.

11.4 Minimizing IR Drop

11.4.1 If an interrupted surface potential gradient survey is desired, the procedures and equipment are similar to those listed in Section 5.

11.5 Pipe Location and Marking Procedures

11.5.1 Pipe location and marking procedures are similar to those listed in Section 6. Accurate pipe location is critical for surface potential gradient surveys, and a more stringent criterion for pipe location and marking than those for close-interval surveys may be necessary.

11.6 Hot-Spot Survey Procedures

11.6.1 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.

11.6.2 Because the voltage values between the reference electrodes are normally low, each reference electrode contact with the earth should be free of leaves, grass, rocks, and other debris. The reference electrodes should 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 can be performed using the methods in Section 10.

11.6.3 Reference electrode spacing should be uniform. Spacing for this type of survey is not determined by methods used in Paragraph 7.2.1. 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.

11.6.4 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.

11.6.5 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 should be given to ensure the polarity of each voltage measurement is recorded correctly.

11.6.6 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 3). The meter shall indicate the polarity of the measured potential.

11.6.7 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 3.

11.6.7.1 A suspected anodic condition is indicated by a change of the instrument polarity indication. The severity and extent of an anodic condition may be further determined by measuring side-drain potentials. These tests are generally made on both sides of the pipe to verify that current is leaving the line, 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.

11.6.7.2 The presence of a galvanic anode connected to the pipe affects surface potential gradient measurements and generally appears as an anodic condition. Close observation of measured values quite often suggests the presence of galvanic anodes. As an 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 data. Any situation not determined to be caused by some other factor is typically considered as an anodic condition.

11.6.8 Data may be recorded on a form having a suitable format or recorded using a data logger. Special attention should be given to ensure the polarity of each voltage measurement is recorded correctly.

11.6.9 Adequate marking or precise survey coordinates 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.

11.7 Side-Drain Survey Procedures

11.7.1 In order to perform a continuous evaluation of the structure, the required survey interval depends only 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.[12] 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.

11.7.2 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 are typically measured to both sides of the pipeline in order to identify conditions like those described in B7.5; however, these conditions may be determined by further testing.

11.7.3 Because the voltage values between the reference electrodes are normally low, the reference electrode contact with the earth should be free of leaves, grass, rocks, and other debris. The reference electrodes should 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 can be performed using the methods in Section 10.

11.7.4 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.

11.7.5 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 4). Using this polarity convention, positive gradients indicate current toward the pipeline, and negative potential gradients indicate current away from the pipeline.

11.7.6 Surface potential gradients indicating current away from the pipeline on both sides of the pipeline indicate a possible anodic condition. See Figure 4.

11.7.7 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.

11.7.8 Data may be recorded on a form having a suitable format or recorded using a data logger. Special attention should be given to ensure the polarity of each voltage measurement is recorded correctly.

11.7.9 Adequate marking or precise survey coordinates 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.

11.8 Data Validity and Post-Job Analysis

11.8.1 Data are not always recorded. In these cases, surveys must be conducted by qualified personnel, and inspection or supervision may be necessary to ensure that a valid survey is obtained.

11.8.2 The surface potential gradient survey data may be used to generate a pipe-to-electrolyte potential gradient curve. The pipe-to-electrolyte potential is measured at a test point, such as a test station. 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 pipe-to-electrolyte potential curve. Alternatively, a plot can be made using other reference potentials such as remote earth.

11.9 Interpretation of survey data

11.9.1 This standard does not address interpretation of survey data. Survey data shall be reviewed and interpreted only by persons qualified such as described in Paragraph 1.3.1 and experienced in these types of data. 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) Unknown pipe resistances;

(f) Physical location of the pipe with respect to other structures; and

(g) Known corrosion leak history.

11.9.2 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.

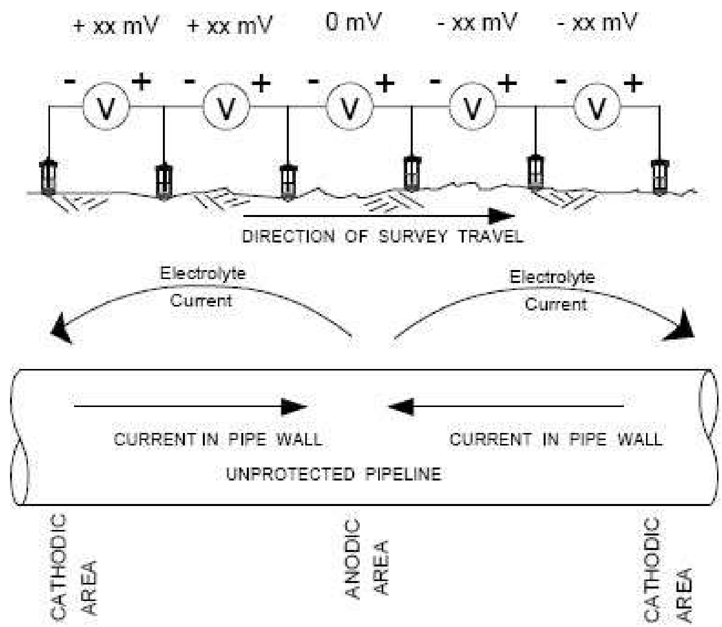

FIGURE 3: Hot-Spot Survey

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.

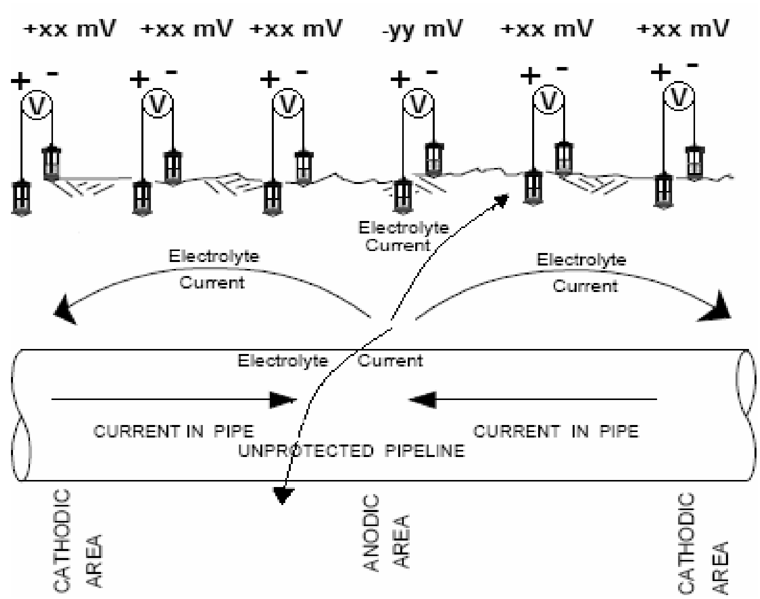

FIGURE 4: Side-Drain Survey

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.

Section 12: Data Validity and Post-Job Analysis

12.1 Introduction

12.1.1 This section describes requirements and recommendations for evaluating CIS data validity and completeness.

12.1.2 CIS data shall be reviewed and interpreted only by persons qualified such as described in Paragraph 1.3.1 and experienced in CIS data.

12.1.3 This section is a general guide to minimum requirements for reviewing and interpreting CIS data, but is not intended to substitute for proper qualifications and experience.

12.1.4 Interpretation of CIS data for use in demonstrating criteria such as those in NACE SP0169[2] shall be made using the requirements set forth in it and in TM0497.[9]

12.1.5 Many errors that can make CIS data invalid 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.

12.2 Validating CIS data

12.2.1 There are many factors that can make CIS data invalid, including:

(a) Missing data;

(b) Improper stationing or distance measurement;

(c) No connection to the structure (an open circuit in the measurement circuit, such as a broken test lead, voltmeter lead, unknown isolating devices, or lack of electrical continuity along the pipeline);

(d) Connection to the wrong structure;

(e) Improper line location or reference electrode placement;

(f) Excessive scatter or high-contact resistance;

(g) Inaccurate or improperly calibrated reference electrodes or voltmeter;

(h) Broken wires/high-resistance electrical connections;

(i) Inadequate wire insulation or electrical short circuits;

(j) Improper/inadequate IR drop correction; and

(k) High-induced AC potentials.

(l) Other causes of measurement error are listed in Section 6 of NACE Standard TM0497.[9]

12.2.2 Other factors can result in potential measurements that are valid, but not representative of actual conditions of the pipeline prior to the survey:

12.2.2.1 Depolarization;

12.2.2.2 Changing conditions such as removing or adding bonds; and

12.2.2.3 Changing CP current source outputs.

12.2.3 All data for a particular pipeline section shall be taken in a suitable time period to ensure similar soil conditions and levels of protection.

12.2.4 A minimum of information is required at the start and end of each survey run (see Paragraphs 7.8.1 through 7.8.3). Missing information may result in a survey run being difficult or impossible to evaluate properly.

12.2.5 Stationing at starting and ending connection points and at key physical features should match station numbers provided. Key physical features should be recorded with the CIS data, and the station number may be updated to match the stationing provided.

12.2.6 Graphs shall indicate the direction in which the survey was performed and should plot the data in a consistent direction regardless of the direction in which the survey was performed.

12.2.7 Graphs should use the same vertical and horizontal scale for plot of contiguous data.

12.2.8 Potential data are valid when potential measurements are made according to the requirements in Sections 4 through 9 of this standard, when applicable, and are distinguishable from scatter.

12.2.8.1 Few CIS can be conducted without some scatter. Scatter is often present even in the best of conditions and with the best surveyors.

12.2.8.2 The goal of a CIS is to obtain potential measurements versus distance. Data that contain scatter can often be interpreted to give this information. The presence of scatter does not automatically make a set of data invalid. The data must be evaluated to determine that the information required can be interpreted.

12.2.8.2.1 The data should be evaluated to determine whether accurate potentials can be distinguished for the areas surveyed. There may be some areas in which the data are uncertain as a result of scatter. The surrounding data are representative of the indeterminate areas when those indeterminate areas are short. Figure 5 is an example of CIS data containing some scatter.

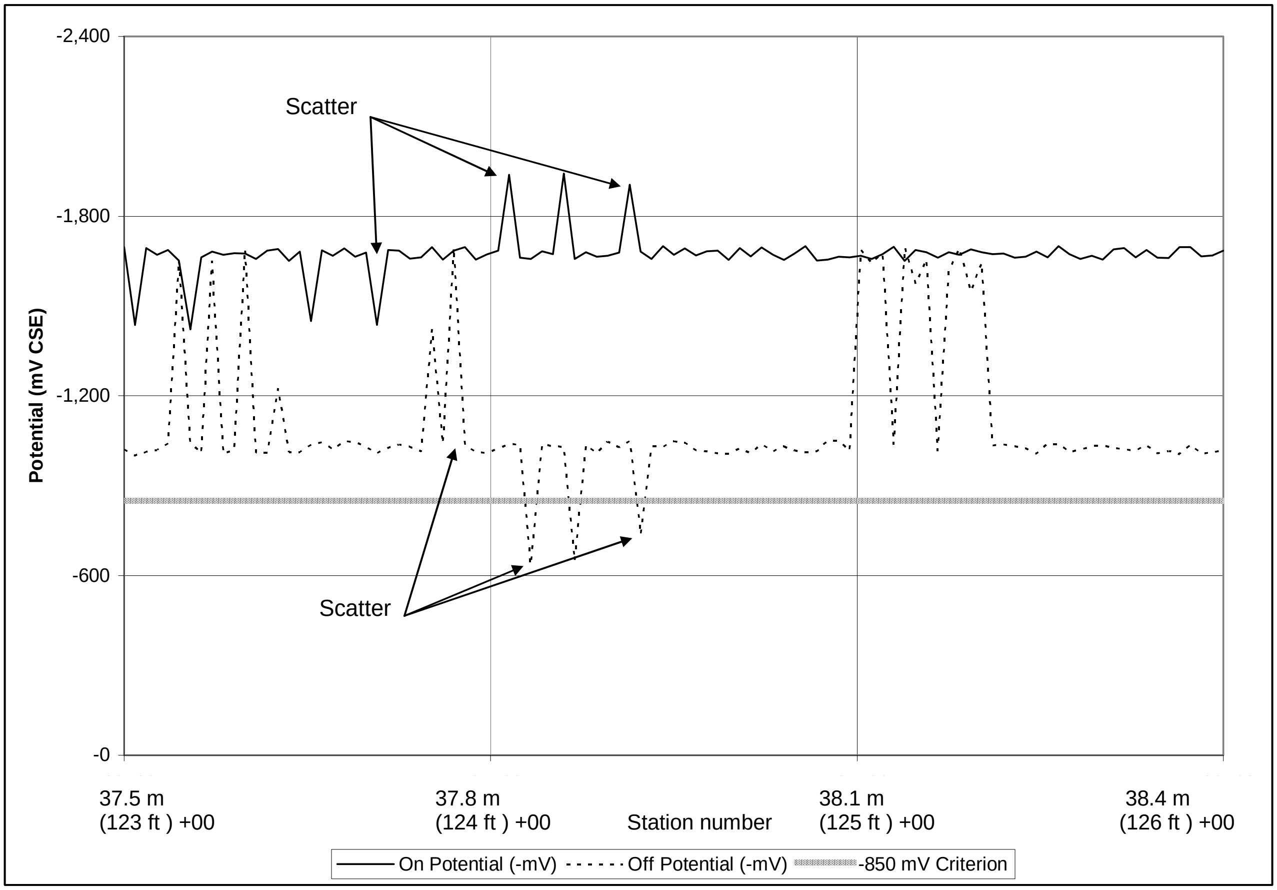

FIGURE 5: Plot of "On" and Instant-Off Potentials vs. Distance with Scatter

12.2.9 A broken lead wire may appear similar to open-circuit potential measurements because of scatter, except that the potentials may be more consistent. If not immediately identified by the surveyor, invalid measurements will be incorporated into the data.

12.2.10 High-resistance connections can introduce error that is not detectable after the survey is performed, except by comparing the structure-to-electrolyte potentials to valid potentials measured at the same location.

12.2.11 Figure 6 shows an example of CIS data with unmatched reference electrodes. One of the cells reads differently from the other, giving a characteristic sawtooth appearance.

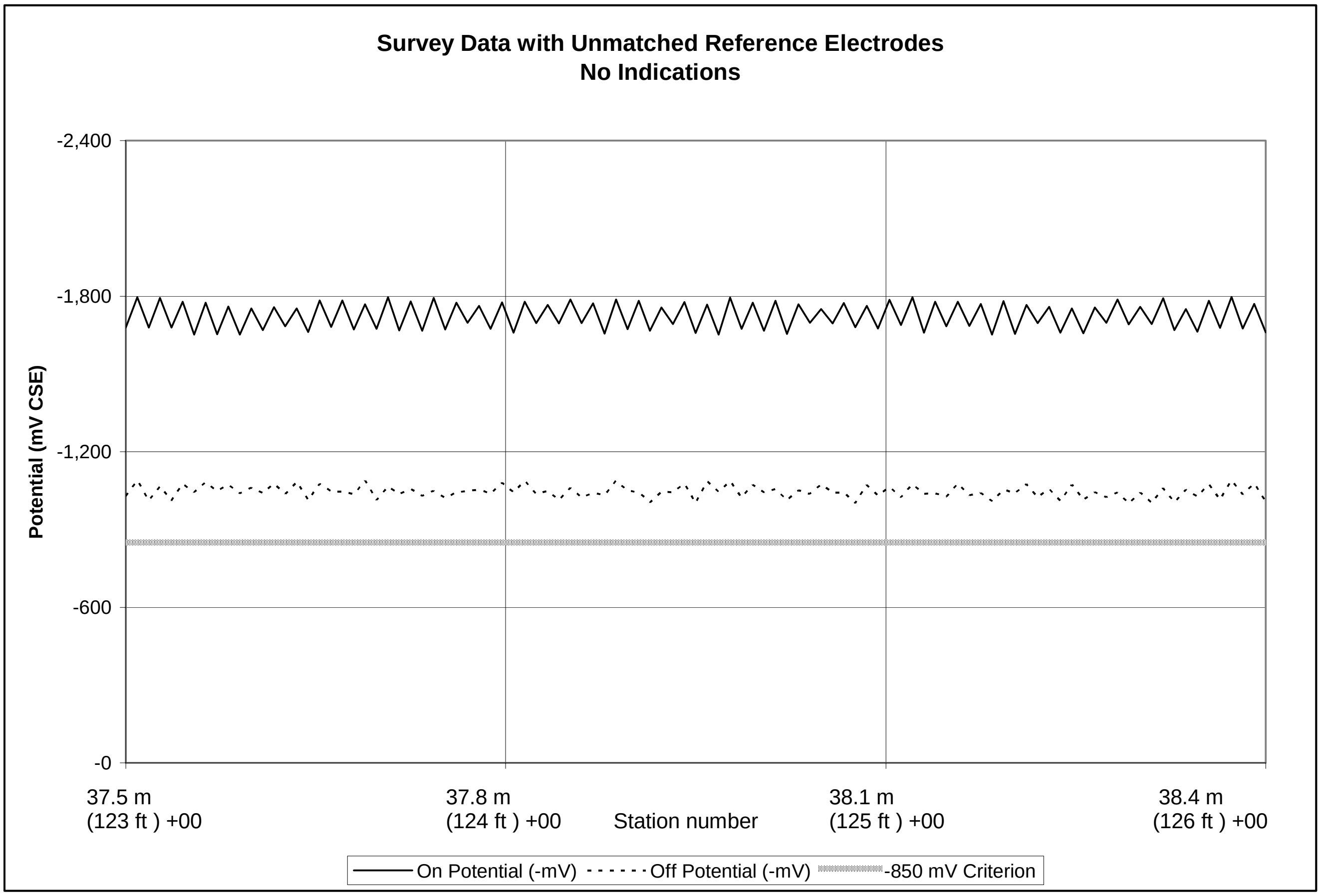

FIGURE 6: Plot of "On" and Instant-Off Potentials vs. Distance with Unmatched Reference Electrodes

12.2.12 Excessively high AC potentials can influence the voltmeter.

12.2.12.1 The effects of excessively high AC potentials are often not detectable based on evaluating the potential data.

12.2.12.2 The survey meter manufacturer's criteria for maximum AC rejection should be followed, and AC potentials should be measured periodically to ensure the criteria are not exceeded.

12.2.12.3 AC potentials can be impressed on the survey wire, and FG AC potentials measured may not be representative of potentials on the structure.

12.2.13 Improper location is usually not detectable based on evaluating CIS data.

12.2.13.1 Steps must be taken to ensure proper pipeline location during the performance of the CIS.

12.2.13.2 "On" potentials measured with the reference electrode to the side of the pipeline are more negative than potentials measured with the reference electrode directly over the pipeline if there is current in the soil toward the pipe, assuming consistent coating conditions, current density, and soil conditions exist.

12.2.13.3 Instant-off or depolarized potentials measured with the reference electrode to the side of the pipeline are the same as potentials measured with the reference electrode directly over the pipeline if there is no current in the electrolyte during the "off" cycle, assuming consistent coating condition, current density, and soil conditions exist.

12.2.13.4 Potentials measured offset to the pipeline have reduced resolution. Each structure-to-electrolyte potential measurement represents a broader range of the pipeline, and may not identify smaller indications.

12.3 Validating IR drop correction

12.3.1 The magnitude of IR drop error remaining in instant-off potentials can usually only be determined indirectly by confirming interruption of influencing CP current sources, measuring lateral potentials, and by measuring metallic IR drop.

12.3.2 Waveprints cannot confirm that all current is interrupted, only that those interrupters operating are synchronized.

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(2) Pipeline Research Council International, Inc. (PRCI), 1401 Wilson Boulevard, Suite 1101, Arlington, VA 22209.
(3) Gas Technology Institute (GTI), 1700 S Mount Prospect Road, Des Plaines, IL 60018.
(4) ASME International (ASME), Three Park Ave., New York, NY 10016-5990.

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APPENDIX A: Pipe IR Drop Calculation (Nonmandatory)

To use Table A1 to obtain current (*I*) in amps, multiply the appropriate factor (*k*) from Table A1 by the metallic IR drop (FG - NG) and divide by the distance (*L*). See Equation (A1):

$$I = k \times \frac{V_{IR,m}}{L} \qquad \text{(A1)}$$

where:

I = Net current along pipeline between connection points
k = Pipe IR drop calculation constant from Table A1
$V_{IR,m}$ = Metallic IR drop determined from (FG - NG)
FG = Far-ground potential
NG = Near-ground potential
L = Length of pipeline between FG and NG connections

Potentials must be expressed in mV, and length must be expressed in consistent units with the pipe IR drop constant (ft or m, for the respective columns). Note that this calculation determines the average current for the interval for a single pipeline, and may not be valid for multiple interconnected pipelines if parallel current paths exist between the FG and NG measurement.

With this polarity convention (FG - NG), a positive value for the current indicates conventional current from the FG connection to the NG connection (the same direction as the survey). For an illustration, see Figure 2 of TM0497.[9] A negative value indicates conventional current from the NG connection to the FG connection (opposite that of the survey direction). See Equations (A2) and (A3).

[(5)] European Federation of Corrosion (EFC), Carlton House Terrace 1, London, England SW 1Y 5DB.

Example A1

FG: -1,154 mV vs. $Cu/CuSO_4$
NG: -1,254 mV vs. $Cu/CuSO_4$
$V_{IR,m}$ = FG - NG = -1,154 - (-1,254) = +100 mV
L = distance between FG connection and NG connection = 3,048 m
From Table A1, for 610-mm outside diameter (OD) 7.14-mm wall pipe in SI units, *k* = 75.0 A-m/mV

$$I = k\left(\frac{V_{IR,m}}{L}\right) = 75.0\left(\frac{100}{3{,}048}\right) = 2.46\ \text{amps} \tag{A2}$$

Example A2

FG: -1,154 mV vs. $Cu/CuSO_4$
NG: -1,254 mV vs. $Cu/CuSO_4$
$V_{IR,m}$ = FG - NG = -1,154 - (-1,254) = +100 mV
L = distance between FG connection and NG connection = 10,000 ft
For 24.0-in. OD 0.28-in. wall pipe in English units, *k* = 246 A-ft/mV

$$I = k\left(\frac{V_{IR,m}}{L}\right) = 246\left(\frac{100}{10{,}000}\right) = 2.46\ \text{amps} \tag{A3}$$

Table A1: Pipe IR Drop Calculation Constants for Welded and Seamless Wrought Steel Pipe(A)

SI Units			U.S. Units			k, Pipe IR Drop Calculation Constant(B)	
Nominal Diameter (DN)(C)	**Outside Diameter (mm)**	**Wall Thickness (mm)**	**Nominal Pipe Size (NPS)(D)**	**Outside Diameter (in.)**	**Wall Thickness (in.)**	**A-ft/ mV**	**A-m/ mV**
150	168.3	2.11	6	6.625	0.083	20.1	6.11
150	168.3	2.77	6	6.625	0.109	26.2	8.00
150	168.3	3.18	6	6.625	0.125	30.0	9.15
150	168.3	3.40	6	6.625	0.134	32.1	9.79
150	168.3	3.58	6	6.625	0.141	33.8	10.3
150	168.3	3.96	6	6.625	0.156	37.3	11.4
150	168.3	4.37	6	6.625	0.172	41.0	12.5
150	168.3	4.78	6	6.625	0.188	44.7	13.6
150	168.3	5.16	6	6.625	0.203	48.2	14.7
150	168.3	5.56	6	6.625	0.219	51.8	15.8
150	168.3	6.35	6	6.625	0.250	58.9	17.9
150	168.3	7.11	6	6.625	0.280	65.6	20.0
150	168.3	7.92	6	6.625	0.312	72.8	22.2
150	168.3	8.74	6	6.625	0.344	79.8	24.3
150	168.3	9.53	6	6.625	0.375	86.6	26.4
150	168.3	10.97	6	6.625	0.432	98.8	30.1
150	168.3	12.70	6	6.625	0.500	113	34.5
150	168.3	14.27	6	6.625	0.562	126	38.4
150	168.3	15.88	6	6.625	0.625	139	42.2
150	168.3	18.26	6	6.625	0.719	157	47.8
150	168.3	19.05	6	6.625	0.750	163	49.6

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant(B)	
Nominal Diameter (DN)(C)	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)(D)	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
150	168.3	21.95	6	6.625	0.864	184	56.0
150	168.3	22.23	6	6.625	0.875	186	56.7
200	219.1	2.77	8	8.625	0.109	34.3	10.5
200	219.1	3.18	8	8.625	0.125	39.3	12.0
200	219.1	3.76	8	8.625	0.148	46.3	14.1
200	219.1	3.96	8	8.625	0.156	48.8	14.9
200	219.1	4.78	8	8.625	0.188	58.6	17.9
200	219.1	5.16	8	8.625	0.203	63.2	19.3
200	219.1	5.56	8	8.625	0.219	68.0	20.7
200	219.1	6.35	8	8.625	0.250	77.3	23.6
200	219.1	7.04	8	8.625	0.277	85.4	26.0
200	219.1	7.92	8	8.625	0.312	95.8	29.2
200	219.1	8.18	8	8.625	0.322	98.8	30.1
200	219.1	8.74	8	8.625	0.344	105	32.1
200	219.1	9.53	8	8.625	0.375	114	34.8
200	219.1	10.31	8	8.625	0.4060	123	37.6
200	219.1	11.13	8	8.625	0.4380	132	40.4
200	219.1	12.70	8	8.625	0.5000	150	45.7
200	219.1	14.27	8	8.625	0.5620	167	51.0
200	219.1	15.09	8	8.625	0.5940	176	53.7
200	219.1	15.88	8	8.625	0.6250	185	56.3
200	219.1	18.26	8	8.625	0.7190	210	64.0
200	219.1	19.05	8	8.625	0.7500	218	66.5
200	219.1	20.62	8	8.625	0.8120	234	71.4
200	219.1	22.23	8	8.625	0.8750	251	76.4
200	219.1	23.01	8	8.625	0.9060	258	78.7
200	219.1	25.40	8	8.625	1.000	282	85.9
250	273.0	3.40	10	10.750	0.134	52.6	16.0
250	273.0	3.96	10	10.750	0.156	61.1	18.6
250	273.0	4.19	10	10.750	0.165	64.5	19.7
250	273.0	4.78	10	10.750	0.188	73.4	22.4
250	273.0	5.16	10	10.750	0.203	79.1	24.1
250	273.0	5.56	10	10.750	0.219	85.2	26.0
250	273.0	6.35	10	10.750	0.250	97.0	29.6
250	273.0	7.09	10	10.750	0.279	108	32.9
250	273.0	7.80	10	10.750	0.307	118	36.1
250	273.0	8.74	10	10.750	0.344	132	40.3
250	273.0	9.27	10	10.750	0.365	140	42.7
250	273.0	11.13	10	10.750	0.4380	167	50.9
250	273.0	12.70	10	10.750	0.5000	189	57.7
250	273.0	14.27	10	10.750	0.5620	212	64.5
250	273.0	15.09	10	10.75	0.5940	223	67.9
250	273.0	15.88	10	10.75	0.6250	234	71.3
250	273.0	18.26	10	10.75	0.7190	266	81.2
250	273.0	20.62	10	10.75	0.8120	298	90.9

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant(B)	
Nominal Diameter (DN)(C)	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)(D)	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
250	273.0	21.44	10	10.75	0.8440	309	94.1
250	273.0	22.23	10	10.75	0.8750	319	97.3
250	273.0	23.83	10	10.75	0.9380	340	104
250	273.0	25.40	10	10.75	1.000	360	110
250	273.0	28.58	10	10.75	1.125	400	122
250	273.0	31.75	10	10.75	1.250	439	134
300	323.8	3.96	12	12.75	0.156	72.6	22.1
300	323.8	4.37	12	12.75	0.172	79.9	24.4
300	323.8	4.57	12	12.75	0.180	83.6	25.5
300	323.8	4.78	12	12.75	0.188	87.2	26.6
300	323.8	5.16	12	12.75	0.203	94.1	28.7
300	323.8	5.56	12	12.75	0.219	101	30.9
300	323.8	6.35	12	12.75	0.250	115	35.2
300	323.8	7.14	12	12.75	0.281	129	39.5
300	323.8	7.92	12	12.75	0.312	143	43.7
300	323.8	8.38	12	12.75	0.330	151	46.2
300	323.8	8.74	12	12.75	0.344	158	48.1
300	323.8	9.53	12	12.75	0.375	171	52.3
300	323.8	10.31	12	12.75	0.4060	185	56.4
300	323.8	11.13	12	12.75	0.4380	199	60.7
300	323.8	12.70	12	12.75	0.5000	226	69.0
300	323.8	14.27	12	12.75	0.5620	253	77.1
300	323.8	15.88	12	12.75	0.6250	280	85.3
300	323.8	17.48	12	12.75	0.6880	307	93.4
300	323.8	19.05	12	12.75	0.7500	332	101
300	323.8	20.62	12	12.75	0.8120	358	109
300	323.8	21.44	12	12.75	0.8440	371	113
300	323.8	22.23	12	12.75	0.8750	384	117
300	323.8	23.83	12	12.75	0.9380	409	125
300	323.8	25.40	12	12.75	1.000	434	132
300	323.8	26.97	12	12.75	1.062	459	140
300	323.8	28.58	12	12.75	1.125	483	147
300	323.8	31.75	12	12.75	1.250	531	162
300	323.8	33.32	12	12.75	1.312	554	169
350	355.6	3.96	14	14.00	0.156	79.8	24.3
350	355.6	4.78	14	14.00	0.188	95.9	29.2
350	355.6	5.16	14	14.00	0.203	103	31.5
350	355.6	5.33	14	14.00	0.210	107	32.6
350	355.6	5.56	14	14.00	0.219	111	34.0
350	355.6	6.35	14	14.00	0.250	127	38.7
350	355.6	7.14	14	14.00	0.281	142	43.4
350	355.6	7.92	14	14.00	0.312	158	48.1
350	355.6	8.74	14	14.00	0.344	174	52.9
350	355.6	9.53	14	14.00	0.375	189	57.5
350	355.6	10.31	14	14.00	0.4060	204	62.1

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant[(B)]	
Nominal Diameter (DN)[(C)]	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)[(D)]	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
350	355.6	11.13	14	14.00	0.4380	219	66.9
350	355.6	11.91	14	14.00	0.4690	234	71.5
350	355.6	12.70	14	14.00	0.5000	249	76.0
350	355.6	14.27	14	14.00	0.5620	279	85.0
350	355.6	15.09	14	14.00	0.5940	294	89.7
350	355.6	15.88	14	14.00	0.6250	309	94.1
350	355.6	17.48	14	14.00	0.6880	338	103
350	355.6	19.05	14	14.00	0.7500	367	112
350	355.6	20.62	14	14.00	0.8120	396	121
350	355.6	22.23	14	14.00	0.8750	424	129
350	355.6	23.83	14	14.00	0.9380	453	138
350	355.6	25.40	14	14.00	1.000	480	146
350	355.6	26.97	14	14.00	1.062	508	155
350	355.6	27.79	14	14.00	1.094	522	159
350	355.6	28.58	14	14.00	1.125	535	163
350	355.6	31.75	14	14.00	1.250	589	179
350	355.6	35.71	14	14.00	1.406	654	199
350	355.6	50.80	14	14.00	2.000	887	270
350	355.6	53.98	14	14.00	2.125	932	284
350	355.6	55.88	14	14.00	2.200	959	292
350	355.6	63.50	14	14.00	2.500	1,060	324
400	406.4	4.19	16	16.00	0.165	96.5	29.4
400	406.4	4.78	16	16.00	0.188	110	33.5
400	406.4	5.16	16	16.00	0.203	118	36.1
400	406.4	5.56	16	16.00	0.219	128	38.9
400	406.4	6.35	16	16.00	0.250	145	44.3
400	406.4	7.14	16	16.00	0.281	163	49.7
400	406.4	7.92	16	16.00	0.312	181	55.1
400	406.4	8.74	16	16.00	0.344	199	60.6
400	406.4	9.53	16	16.00	0.375	216	66.0
400	406.4	10.31	16	16.00	0.4060	234	71.3
400	406.4	11.13	16	16.00	0.4380	252	76.8
400	406.4	11.91	16	16.00	0.4690	269	82.0
400	406.4	12.70	16	16.00	0.5000	286	87.3
400	406.4	14.27	16	16.00	0.5620	321	97.7
400	406.4	15.88	16	16.00	0.6250	355	108
400	406.4	16.66	16	16.00	0.656	372	113
400	406.4	17.48	16	16.00	0.688	389	119
400	406.4	19.05	16	16.00	0.750	423	129
400	406.4	20.62	16	16.00	0.812	456	139
400	406.4	21.44	16	16.00	0.844	473	144
400	406.4	22.23	16	16.00	0.875	489	149
400	406.4	23.83	16	16.00	0.938	522	159
400	406.4	25.40	16	16.00	1.000	554	169
400	406.4	26.19	16	16.00	1.031	570	174

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant(B)	
Nominal Diameter (DN)(C)	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)(D)	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
400	406.4	26.97	16	16.00	1.062	586	179
400	406.4	28.58	16	16.00	1.125	618	188
400	406.4	30.18	16	16.00	1.188	650	198
400	406.4	30.96	16	16.00	1.219	666	203
400	406.4	31.75	16	16.00	1.250	681	208
400	406.4	36.53	16	16.00	1.438	774	236
400	406.4	40.49	16	16.00	1.594	848	259
450	457	4.19	18	18.0	0.165	109	33.1
450	457	4.78	18	18.0	0.188	124	37.7
450	457	5.56	18	18.0	0.219	144	43.8
450	457	6.35	18	18.0	0.250	164	50.0
450	457	7.14	18	18.0	0.281	184	56.1
450	457	7.92	18	18.0	0.312	204	62.1
450	457	8.74	18	18.0	0.344	224	68.4
450	457	9.53	18	18.0	0.375	244	74.4
450	457	10.31	18	18.0	0.4060	264	80.4
450	457	11.13	18	18.0	0.4380	284	86.6
450	457	11.91	18	18.0	0.4690	304	92.6
450	457	12.70	18	18.0	0.5000	323	98.5
450	457	14.27	18	18.0	0.5620	362	110
450	457	15.88	18	18.0	0.6250	401	122
450	457	17.48	18	18.0	0.6880	440	134
450	457	19.05	18	18.0	0.7500	478	146
450	457	20.62	18	18.0	0.8120	516	157
450	457	22.23	18	18.0	0.8750	554	169
450	457	23.83	18	18.0	0.9380	591	180
450	457	25.40	18	18.0	1.000	628	191
450	457	26.97	18	18.0	1.062	665	203
450	457	28.58	18	18.0	1.125	701	214
450	457	29.36	18	18.0	1.156	719	219
450	457	30.18	18	18.0	1.188	738	225
450	457	31.75	18	18.0	1.250	773	236
450	457	34.93	18	18.0	1.375	844	257
450	457	39.67	18	18.0	1.562	949	289
450	457	45.24	18	18.0	1.781	1,070	325
500	508	4.78	20	20.0	0.188	138	41.9
500	508	5.56	20	20.0	0.219	160	48.8
500	508	6.35	20	20.0	0.250	182	55.6
500	508	7.14	20	20.0	0.281	205	62.4
500	508	7.92	20	20.0	0.312	227	69.2
500	508	8.74	20	20.0	0.344	250	76.1
500	508	9.53	20	20.0	0.375	272	82.9
500	508	10.31	20	20.0	0.4060	294	89.6
500	508	11.13	20	20.0	0.4380	317	96.5
500	508	11.91	20	20.0	0.4690	338	103

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant(B)	
Nominal Diameter (DN)(C)	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)(D)	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
500	508	12.70	20	20.0	0.5000	360	110
500	508	14.27	20	20.0	0.5620	404	123
500	508	15.09	20	20.0	0.5940	426	130
500	508	15.88	20	20.0	0.6250	447	136
500	508	17.48	20	20.0	0.6880	491	150
500	508	19.05	20	20.0	0.7500	533	163
500	508	20.62	20	20.0	0.8120	576	175
500	508	22.23	20	20.0	0.8750	618	188
500	508	23.83	20	20.0	0.9380	661	201
500	508	25.40	20	20.0	1.000	702	214
500	508	26.19	20	20.0	1.031	722	220
500	508	26.97	20	20.0	1.062	743	226
500	508	28.58	20	20.0	1.125	784	239
500	508	30.18	20	20.0	1.188	826	252
500	508	31.75	20	20.0	1.250	866	264
500	508	32.54	20	20.0	1.281	886	270
500	508	33.32	20	20.0	1.312	906	276
500	508	34.93	20	20.0	1.375	946	288
500	508	38.10	20	20.0	1.500	1,030	312
500	508	44.45	20	20.0	1.750	1,180	360
500	508	50.01	20	20.0	1.969	1,310	400
...	559	4.78	22	22.0	0.188	151	46.2
...	559	5.56	22	22.0	0.219	176	53.7
...	559	6.35	22	22.0	0.250	201	61.2
...	559	7.14	22	22.0	0.281	225	68.7
...	559	7.92	22	22.0	0.312	250	76.2
...	559	8.74	22	22.0	0.344	275	83.9
...	559	9.53	22	22.0	0.375	300	91.3
...	559	10.31	22	22.0	0.4060	324	98.7
...	559	11.13	22	22.0	0.4380	349	106
...	559	11.91	22	22.0	0.4690	373	114
...	559	12.70	22	22.0	0.5000	397	121
...	559	14.27	22	22.0	0.5620	445	136
...	559	15.88	22	22.0	0.6250	494	150
...	559	17.48	22	22.0	0.6880	542	165
...	559	19.05	22	22.0	0.7500	589	179
...	559	20.62	22	22.0	0.8120	636	194
...	559	22.23	22	22.0	0.8750	683	208
...	559	23.83	22	22.0	0.9380	730	222
...	559	25.40	22	22.0	1.000	776	236
...	559	26.97	22	22.0	1.062	821	250
...	559	28.58	22	22.0	1.125	868	264
...	559	30.18	22	22.0	1.188	913	278
...	559	31.75	22	22.0	1.250	958	292
...	559	33.32	22	22.0	1.312	1,000	306.0

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant[B]	
Nominal Diameter (DN)[C]	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)[D]	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
...	559	34.93	22	22.0	1.375	1,050	319.0
...	559	36.53	22	22.0	1.438	1,090	333.0
...	559	38.10	22	22.0	1.500	1,140	346.0
...	559	41.28	22	22.0	1.625	1,220	373.0
...	559	47.63	22	22.0	1.875	1,390	425.0
...	559	53.98	22	22.0	2.125	1,560	476.0
600	610	5.54	24	24.0	0.218	192	58.4
600	610	6.35	24	24.0	0.250	219	66.9
600	610	7.14	24	24.0	0.281	246	75.0
600	610	7.92	24	24.0	0.312	273	83.2
600	610	8.74	24	24.0	0.344	301	91.6
600	610	9.53	24	24.0	0.375	327	99.8
600	610	10.31	24	24.0	0.4060	354	108
600	610	11.13	24	24.0	0.4380	381	116
600	610	11.91	24	24.0	0.4690	408	124
600	610	12.70	24	24.0	0.5000	434	132
600	610	14.27	24	24.0	0.5620	487	148
600	610	15.88	24	24.0	0.6250	540	165
600	610	17.48	24	24.0	0.6880	593	181
600	610	19.05	24	24.0	0.7500	644	196
600	610	20.62	24	24.0	0.8120	696	212
600	610	22.23	24	24.0	0.8750	748	228
600	610	23.83	24	24.0	0.9380	799	244
600	610	24.61	24	24.0	0.9690	824	251
600	610	25.40	24	24.0	1.000	850	259
600	610	26.97	24	24.0	1.062	900	274
600	610	28.58	24	24.0	1.125	951	290
600	610	30.18	24	24.0	1.188	1,000	305
600	610	30.96	24	24.0	1.219	1,030	313
600	610	31.75	24	24.0	1.250	1,050	320.00
600	610	33.32	24	24.0	1.312	1,100	335.00
600	610	34.93	24	24.0	1.375	1,150	350.00
600	610	36.53	24	24.0	1.438	1,200	365.00
600	610	38.10	24	24.0	1.500	1,250	380.00
600	610	38.89	24	24.0	1.531	1,270	387.00
600	610	39.67	24	24.0	1.562	1,290	395.00
600	610	46.02	24	24.0	1.812	1,490	453.00
600	610	52.37	24	24.0	2.062	1,670	509.00
600	610	59.54	24	24.0	2.344	1,880	572.00
...	660	6.35	26	26.0	0.250	238	72.5
...	660	7.14	26	26.0	0.281	267	81.4
...	660	7.92	26	26.0	0.312	296	90.2
...	660	8.74	26	26.0	0.344	326	99.4
...	660	9.53	26	26.0	0.375	355	108
...	660	10.31	26	26.0	0.4060	384	117

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant(B)	
Nominal Diameter (DN)(C)	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)(D)	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
...	660	11.13	26	26.0	0.4380	414	126
...	660	11.91	26	26.0	0.4690	442	135
...	660	12.70	26	26.0	0.5000	471	144
...	660	14.27	26	26.0	0.5620	528	161
...	660	15.88	26	26.0	0.6250	586	179
...	660	17.48	26	26.0	0.6880	643	196
...	660	19.05	26	26.0	0.7500	700	213
...	660	20.62	26	26.0	0.8120	756	230
...	660	22.23	26	26.0	0.8750	812	248
...	660	23.83	26	26.0	0.9380	868	265
...	660	25.40	26	26.0	1.000	924	282
700	711	6.35	28	28.0	0.250	256	78.1
700	711	7.14	28	28.0	0.281	288	87.7
700	711	7.92	28	28.0	0.312	319	97.3
700	711	8.74	28	28.0	0.344	351	107
700	711	9.53	28	28.0	0.375	383	117
700	711	10.31	28	28.0	0.4060	414	126
700	711	11.13	28	28.0	0.4380	446	136
700	711	11.91	28	28.0	0.4690	477	145
700	711	12.70	28	28.0	0.5000	508	155
700	711	14.27	28	28.0	0.5620	570	174
700	711	15.88	28	28.0	0.6250	632	193
700	711	17.48	28	28.0	0.6880	694	212
700	711	19.05	28	28.0	0.7500	755	230
700	711	20.62	28	28.0	0.8120	816	249
700	711	22.23	28	28.0	0.8750	877	267
700	711	23.83	28	28.0	0.9380	938	286
700	711	25.40	28	28.0	1.000	997	304
...	762	6.35	30	30.0	0.250	275	83.7
...	762	7.14	30	30.0	0.281	309	94.0
...	762	7.92	30	30.0	0.312	342	104
...	762	8.74	30	30.0	0.344	377	115
...	762	9.53	30	30.0	0.375	410	125
...	762	10.31	30	30.0	0.4060	444	135
...	762	11.13	30	30.0	0.4380	478	146
...	762	11.91	30	30.0	0.4690	512	156
...	762	12.70	30	30.0	0.5000	545	166
...	762	14.27	30	30.0	0.5620	611	186
...	762	15.88	30	30.0	0.6250	678	207
...	762	17.48	30	30.0	0.6880	745	227
...	762	19.05	30	30.0	0.7500	810	247
...	762	20.62	30	30.0	0.8120	876	267
...	762	22.23	30	30.0	0.8750	941	287
...	762	23.83	30	30.0	0.9380	1,010	307
...	762	25.40	30	30.0	1.000	1,070	327

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant(B)	
Nominal Diameter (DN)(C)	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)(D)	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
...	762	26.97	30	30.0	1.062	1,140	346
...	762	28.58	30	30.0	1.125	1,200	366
...	762	30.18	30	30.0	1.188	1,260	385
...	762	31.75	30	30.0	1.250	1,330	405
800	813	6.35	32	32.0	0.250	293	89.4
800	813	7.14	32	32.0	0.281	329	100
800	813	7.92	32	32.0	0.312	365	111
800	813	8.74	32	32.0	0.344	402	123
800	813	9.53	32	32.0	0.375	438	134
800	813	10.31	32	32.0	0.4060	474	144
800	813	11.13	32	32.0	0.4380	511	156
800	813	11.91	32	32.0	0.4690	546	167
800	813	12.70	32	32.0	0.5000	582	177
800	813	14.27	32	32.0	0.5620	653	199
800	813	15.88	32	32.0	0.6250	724	221
800	813	17.48	32	32.0	0.6880	796	243
800	813	19.05	32	32.0	0.7500	866	264
800	813	20.62	32	32.0	0.8120	936	285
800	813	22.23	32	32.0	0.8750	1,010	307
800	813	23.83	32	32.0	0.9380	1,080	328
800	813	25.40	32	32.0	1.000	1,150	349
800	813	26.97	32	32.0	1.062	1,210	370
800	813	28.58	32	32.0	1.125	1,280	391
800	813	30.18	32	32.0	1.188	1,350	412
800	813	31.75	32	32.0	1.250	1,420	433
...	864	6.35	34	34.0	0.250	312	95.0
...	864	7.14	34	34.0	0.281	350	107
...	864	7.92	34	34.0	0.312	388	118
...	864	8.74	34	34.0	0.344	428	130
...	864	9.53	34	34.0	0.375	466	142
...	864	10.31	34	34.0	0.4060	504	154
...	864	11.13	34	34.0	0.4380	543	166
...	864	11.91	34	34.0	0.4690	581	177
...	864	12.70	34	34.0	0.5000	619	189
...	864	14.27	34	34.0	0.5620	694	212
...	864	15.88	34	34.0	0.6250	771	235
...	864	17.48	34	34.0	0.6880	847	258
...	864	19.05	34	34.0	0.7500	921	281
...	864	20.62	34	34.0	0.8120	996	303
...	864	22.23	34	34.0	0.8750	1,070	326
...	864	23.83	34	34.0	0.9380	1,150	349
...	864	25.40	34	34.0	1.000	1,220	372
...	864	26.97	34	34.0	1.062	1,290	394
...	864	28.58	34	34.0	1.125	1,370	416
...	864	30.18	34	34.0	1.188	1,440	439

	SI Units			U.S. Units		k, Pipe IR Drop Calculation Constant(B)	
Nominal Diameter (DN)(C)	Outside Diameter (mm)	Wall Thickness (mm)	Nominal Pipe Size (NPS)(D)	Outside Diameter (in.)	Wall Thickness (in.)	A-ft/ mV	A-m/ mV
...	864	31.75	34	34.0	1.250	1,510	461
900	914	6.35	36	36.0	0.250	330	101
900	914	7.14	36	36.0	0.281	371	113
900	914	7.92	36	36.0	0.312	411	125
900	914	8.74	36	36.0	0.344	453	138
900	914	9.53	36	36.0	0.375	494	150
900	914	10.31	36	36.0	0.4060	534	163
900	914	11.13	36	36.0	0.4380	575	175
900	914	11.91	36	36.0	0.4690	616	188
900	914	12.70	36	36.0	0.5000	656	200
900	914	14.27	36	36.0	0.5620	736	224
900	914	15.88	36	36.0	0.6250	817	249
900	914	17.48	36	36.0	0.6880	898	274
900	914	19.05	36	36.0	0.7500	977	298
900	914	20.62	36	36.0	0.8120	1,060	322
900	914	22.23	36	36.0	0.8750	1,140	346
900	914	23.83	36	36.0	0.9380	1,210	370
900	914	25.40	36	36.0	1.000	1,290	394
900	914	26.97	36	36.0	1.062	1,370	418
900	914	28.58	36	36.0	1.125	1,450	442
900	914	30.18	36	36.0	1.188	1,530	466
900	914	31.75	36	36.0	1.250	1,600	489
…	965	7.92	38	38.0	0.312	434	132
…	965	8.74	38	38.0	0.344	479	146
…	965	9.53	38	38.0	0.375	521	159
…	965	10.31	38	38.0	0.4060	564	172
…	965	11.13	38	38.0	0.4380	608	185
…	965	11.91	38	38.0	0.4690	650	198
…	965	12.70	38	38.0	0.5000	693	211
…	965	14.27	38	38.0	0.5620	777	237
…	965	15.88	38	38.0	0.6250	863	263
…	965	17.48	38	38.0	0.6880	948	289
…	965	19.05	38	38.0	0.7500	1,030	315
…	965	20.62	38	38.0	0.8120	1,120	340
…	965	22.23	38	38.0	0.8750	1,200	366
…	965	23.83	38	38.0	0.9380	1,280	391
…	965	25.40	38	38.0	1.000	1,370	417
…	965	26.97	38	38.0	1.062	1,450	442
…	965	28.58	38	38.0	1.125	1,530	467
…	965	30.18	38	38.0	1.188	1,620	492
…	965	31.75	38	38.0	1.250	1,700	517
1,000	1,016	7.92	40	40.00	0.312	457	139
1,000	1,016	8.74	40	40.00	0.344	504	154
1,000	1,016	9.53	40	40.00	0.375	549	167
1,000	1,016	10.31	40	40.00	0.4060	594	181

	SI Units			**U.S. Units**		**k, Pipe IR Drop Calculation Constant**[(B)]	
Nominal Diameter (DN)[(C)]	**Outside Diameter (mm)**	**Wall Thickness (mm)**	**Nominal Pipe Size (NPS)**[(D)]	**Outside Diameter (in.)**	**Wall Thickness (in.)**	**A-ft/ mV**	**A-m/ mV**
1,000	1,016	11.13	40	40.00	0.4380	640	195
1,000	1,016	11.91	40	40.00	0.4690	685	209
1,000	1,016	12.70	40	40.00	0.5000	730	222
1,000	1,016	14.27	40	40.00	0.5620	819	250
1,000	1,016	15.88	40	40.00	0.6250	909	277
1,000	1,016	17.48	40	40.00	0.6880	999	305
1,000	1,016	19.05	40	40.00	0.7500	1,090	331
1,000	1,016	20.62	40	40.00	0.8120	1,180	358
1,000	1,016	22.23	40	40.00	0.8750	1,260	385
1,000	1,016	23.83	40	40.00	0.9380	1,350	413
1,000	1,016	25.40	40	40.00	1.000	1,440	439
1,000	1,016	26.97	40	40.00	1.062	1,530	466
1,000	1,016	28.58	40	40.00	1.125	1,620	492
1,000	1,016	30.18	40	40.00	1.188	1,700	519
1,000	1,016	31.75	40	40.00	1.250	1,790	545

(A) Information in Table A1 based on Table 1 of ASME B36.10M.[13]
(B) An average value of 18 µΩ·cm for the resistivity of steel from *Peabody's Control of Pipeline Corrosion* was used.[14] Pipe with a nominal diameter of 304.8 mm (12 in.) and smaller, or any pipe made prior to around 1972, is generally composed of a mild steel alloy with a bulk resistivity of about 13.45 µΩ·cm. Correction for resistivities of other materials can be made by multiplying the constant k by the ratio of this average value to the actual resistivity. This calculation assumes that the resistances of the connections are the same as that calculated using the bulk resistivity of the material. For connections with significantly higher resistance, the connection resistances should be summed and added to the total resistance of the pipeline using the manual calculation methods (see Example A4). Note that this calculation determines the average current for the interval for a single pipeline, and may not be valid for multiple interconnected pipelines if parallel current paths exist between the FG and NG measurement.
(C) DN (nominal diameter) is a dimensionless designator used in the SI (metric) system to describe pipe size.
(D) NPS (nominal pipe size) is a dimensionless designator that has been substituted in the customary units section for the previous term inch nominal size.

Manual Calculation of Pipe IR Drop

Alternatively, the current can be calculated using Equations (A4) through (A8):

Ohm's Law:

$$I = \frac{V_{IR,m}}{R} \tag{A4}$$

Definition of resistivity:

$$\rho = \frac{RA}{L} \tag{A5}$$

Cross-sectional area of an annulus:

$$A = \frac{\pi\left(D_o^{\,2} - D_i^{\,2}\right)}{4} \tag{A6}$$

Inside diameter of a pipe:

$$D_i = D_o - 2t \tag{A7}$$

Combining equations (A4) though (A7):

$$I = \frac{\pi\left(D_o^{\,2} - [D_o - 2t]^2\right)(FG - NG)}{4\,\rho L} \tag{A8}$$

Where:

I = Net current along pipeline between connection points
$V_{IR,m}$ = Metallic IR voltage drop due to pipe electrical resistance = (FG - NG)
FG = Far-ground potential
NG = Near-ground potential
ρ = Resistivity of pipeline material
R = Resistance of pipeline
L = Length of pipeline between FG and NG connections
D_o = Outside diameter of pipe
D_i = Inside diameter of pipe
t = Pipe wall thickness

Diameter, wall thickness, length, resistivity, and potentials must be expressed in consistent units. Note that this calculation determines the average current for the interval for a single pipeline, and may not be valid for multiple interconnected pipelines if parallel current paths exist between the FG and NG measurement. This calculation assumes that the resistances of the connections are the same as that calculated using the bulk resistivity of the material. For connections with significantly higher resistance, the connection resistances should be summed and added to the total resistance of the pipeline.

With this polarity convention (FG - NG), a positive value for the current indicates conventional current from the FG connection to the NG connection (the same direction as the survey). For an illustration, see Figure 2 in TM0497.[9] A negative value indicates conventional current from the NG connection to the FG connection (opposite that of the survey direction).

<u>Example A3</u>

FG = -1,154 mV versus CSE = -1.154 V
NG = -1,254 mV versus CSE= -1.254 V
ρ = 18 μΩ·cm = 0.000018 Ω·cm
L = 3,048 m = 304,800 cm
D_o = 610 mm = 61 cm
t = 7.14 mm = 0.714 cm

$$I = \frac{\pi\left(61^2 - (61 - 2\times 0.714)^2\right)(-1.154 + 1.254)}{4\,(0.000018)\,(304{,}800)} = 2.46 \text{ amps} \qquad \text{(A9)}$$

<u>Example A4</u>

FG = -1,154 mV versus $Cu\text{-}CuSO_4$ = -1.154 V
NG = -1,254 mV versus $Cu\text{-}CuSO_4$ = -1.254 V
ρ = 18 μΩ·cm = 0.000018 Ω·cm
L = 3,048 m = 304,800 cm
D_o = 610 mm = 61 cm
t = 7.14 mm = 0.714 cm

For 305-mm (1-ft) jumpers of 6 mm^2 (No. 10 AWG) copper wire, the connection resistance is approximately 0.0010 Ω each.

$R_{c,n}$ = Resistance of each connection = 0.0010 Ω

For 12-m (40-ft) joints, the number of connections is:

n = Number of connections = L/40 = 3,048/12 = 254

The total resistance of the connections is:

$R_{c,n}$= Total resistance of connections = n $R_{c,n}$ = 0.254 Ω

R_p = Total resistance of pipe = ρL/A = 0.000018 (304800) (4)/π {61^2-[61-2 (0.714)]^2} = 0.041 Ω

The total resistance of the circuit = R_p + $R_{c,n}$ = 0.041 + 0.254 = 0.295 Ω

$$I = \frac{(-1.154 + 1.254)}{0.295} = 0.339 \text{ amps} \qquad \text{(A10)}$$

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