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Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring

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ABSTRACT

This standard practice presents guidelines and procedures for use during risk assessment, mitigation, and monitoring of corrosion on underground, cathodically protected steel piping systems caused by proximity to alternating current (AC) power supply systems.

As shared right-of-way and utility corridor practices become more common, AC influence on adjacent metallic structures has greater significance, and corrosion due to AC influence becomes of greater concern. This standard is not intended to supersede or replace existing corrosion control standards, but rather to complement these standards when the influence of AC-powered systems becomes significant.

The effects of lightning and AC power transmission systems on human safety are not covered by this standard. However, the mitigation measures implemented for safety and system protection, as outlined in NACE SP0177, can also be used for AC corrosion control and are cited whenever feasible.

KEYWORDS

Cathodic protection, alternating current (AC), pipeline, corrosion.

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Foreword

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

This standard practice presents guidelines and procedures for use during risk assessment, mitigation, and monitoring corrosion on underground, cathodically protected steel piping systems caused by proximity to alternating current (AC) power supply systems. This standard is not intended to supersede or replace existing corrosion control standards, but rather to complement these standards when the influence of AC-powered systems becomes significant.

As shared right-of-way and utility corridor practices become more common, AC influence on adjacent metallic structures has greater significance, and corrosion due to AC influence becomes of greater concern.

The effects of lightning and AC power transmission systems on human safety are not covered by this standard. However, the mitigation measures implemented for safety and system protection, as outlined in NACE SP0177, can also be used for AC corrosion control and are cited whenever feasible.[1]

The original technical background for this standard is the NACE Technical Committee Report "AC Corrosion State-of-the-Art: Corrosion Rate, Mechanism, and Mitigation Requirements" prepared by NACE Task Group 327 and published by NACE in January 2010.[2] Supplements to the current understanding of AC corrosion and criteria for this have been made in PRCI[(1)] reports[3,4] published in October 2016.

This standard addresses typical power transmission frequencies up to 60 Hz only.

This standard was prepared by Task Group (TG) 430 on "AC Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring" in 2018. TG 430 is administered by Specific Technology Group (STG) 05 on Cathodic/Anodic Protection and sponsored by STG 35 on Pipelines. This standard is issued by NACE under the auspices of STG 05.

[(1)] Pipeline Research Council International (PRCI), 1401 Wilson Blvd., Ste. 1101, Arlington, VA 22209.

Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring

Section 1: General

1.1 AC (alternating current) corrosion is defined as corrosion initiated and propagating under the influence of alternating current. AC corrosion on cathodically protected underground pipelines is commonly the result of a combined action of the AC voltage, the cathodic protection conditions, a coating defect—usually small—and the chemical and physical conditions of the soil. If the AC component is either entirely removed or limited to a certain level, the corrosion will be mitigated.

AC corrosion is also influenced by direct current (DC). As such, in addition to mitigation by limiting the AC component, AC corrosion can be reduced by adjusting the DC-component – through the cathodic protection (CP) system.

1.2 An AC corrosion evaluation process (Figure 1) should include an analysis which results in development and implementation of a mitigation strategy, development of a monitoring strategy, and implementation of that monitoring strategy. If subsequent monitoring indicates risk of AC corrosion, the analysis as such should be reviewed, the mitigation strategy should be improved, or—in case values of the monitoring parameter are violated but it is documented that this does not lead to corrosion—the monitoring strategy can be modified.

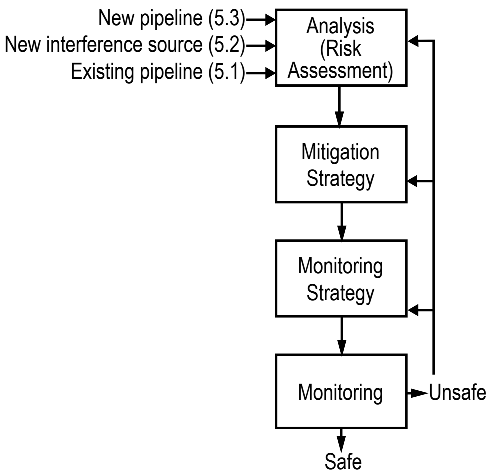

Figure 1: AC Corrosion Evaluation Process

1.3 The provisions of this standard should be applied under the direction of competent persons, who, by reason of knowledge of the physical sciences as well as the principles of engineering and mathematics, acquired by education and related practical experience, are qualified to engage in the practice of corrosion control of buried ferrous piping systems. Such persons may be registered professional engineers or persons recognized as corrosion specialists or CP specialists by NACE if their professional activities include suitable experience in external corrosion control on buried ferrous piping systems and AC interference and mitigation.

1.4 This standard should be used in conjunction with the references contained herein.

Section 2: Definitions

AC Corrosion: Corrosion initiated and propagating under the influence of alternating current.

AC Current Density (J_{AC}): Unit: A/m^2. The AC current density in a coating defect or in a coupon or probe used to simulate a coating defect of a certain area.

AC-Voltage (U_{AC}): Unit: V. Difference in AC potential between the pipeline and the earth. The AC voltage is the ultimate driving force for the AC current density at a coating defect —which may cause corrosion—or the AC current density at grounding devices (including galvanic anodes) installed for mitigation purposes. The AC voltage is not a constant value since:

- it will change over time primarily due to intermittent conditions in the AC power system, for instance because household power consumption is different during daytime and nighttime.
- it will change along the length of the pipeline since the induced voltage depends on characteristics of the pipeline, characteristics of the interfering AC power system, as well as the geometrical and geographical alignment.

AC Voltage Survey: Measurements along the pipeline designed to provide evidence of the actual level of AC pipe to electrolyte potentials or Coating Stress Voltage resulting from existing AC interference sources.

Coating Stress Voltage (AC voltage with respect to close earth): Unit: V. Difference in AC potential between the metallic surface of a coated structure and the earth in contact with the outer surface of the coating. Circuit theory and computer simulations illustrate that the coating stress voltage is, more accurately, the driving force for the AC current density at coating defects when AC mitigation in the form of ribbon anodes is installed in the proximity of the coating defect.

DC Current Density (J_{DC}): Unit A/m^2. The DC current density at a coating defect or at a coupon or probe used to simulate a coating defect of a certain area.

Excessive cathodic protection (CP): Cathodic protection levels that lead to cathodic protection DC current densities exceeding 1 A/m^2 or cathodic protection levels that lower the spread resistance due to cathodic reactions.

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

ON Potential (E_{ON}): Unit: V. DC potential measured between the pipeline and a reference electrode placed in the adjacent soil while the cathodic protection current is flowing. This potential includes voltage drops in the soil (IR drops).

Polarized Potential: Unit: V and **instant OFF-Potentia**l are used interchangeably. The terms refer to pipe to electrolyte DC potential excluding the voltage-drop error associated with the current flowing from a cathodic protection system. The measured OFF potential may include a voltage drop associated with circulating exchange current between anodic and cathodic areas at the pipe.

Spread Resistance (R_S): Unit: $\Omega \cdot m^2$. Refers to the resistance from the pipe to earth through a specific coating defect, or of a coupon or probe of known area, to earth. The spread resistance multiplied by the DC current density constitutes the voltage drop mentioned above, and the spread resistance is (approximately) the proportionality factor between AC voltage and AC current density.

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

Other parameters and definitions not mentioned above are in accordance with NACE standards, practices and reports identified in the References list.

Section 3: Sources of AC

3.1 The AC may be imposed on the pipeline in several ways as described in NACE SP0177.[1] The main source of AC interference is adjacent AC power systems such as high voltage power lines or AC power systems for AC driven trains.

3.2 Three coupling mechanisms exist between the pipeline and the power systems: inductive coupling, resistive coupling, and capacitive coupling. It is understood that inductive coupling is the main contribution to AC corrosion when dealing with long term (i.e. steady state) AC interference.

Section 4: Basic Understanding of AC Corrosion

When AC corrosion develops, this typically involves the steps illustrated in Figure 2 as discussed below.

4.1 For pipelines with cathodic protection applied in accordance with usual criteria,[5] the development of AC corrosion requires simultaneous co-existence of induced AC, excessive cathodic protection, and small coating defects. Threshold values are given in Section 6 (Criteria) of this document.

4.1.1 The induced AC will lead to the discharge of AC current at coating defects, the intensity of which (AC current density) is measured in A/m^2.

4.1.2 The AC current density will be governed by the AC voltage (coating stress voltage) and the spread resistance, associated with the coating defect, through Ohm's Law.

4.1.3 The spread resistance is governed by the size of the coating defect, the soil resistivity at the coating defect, the chemistry of the soil, and by the cathodic protection current density in the coating defect.

4.2 The AC current density may lead to DC depolarization. This means that a higher CP (DC) current density is required to maintain a certain cathodic protection potential.

4.3 Increasing the level of cathodic protection may be attempted in order to mitigate AC corrosion. However, in the AC corrosion scenario, this will have the opposite effect, since the increase of CP current density further decreases the spread resistance at the coating defect due to the production of ions such as OH^- (alkalization). It is noted that the spread resistance may also increase rather than decrease under CP conditions as a result of the formation of high resistive films, such as magnesium- or calcium hydroxides or -oxides, on the steel surface at elevated pH conditions, if these earth alkaline cations are present in the soil. These conditions then lead to a decreased AC corrosion risk.

4.4 Through elevated levels of CP (Paragraphs 4.2 and 4.3), the spread resistance will decrease, thereby increasing the AC current density. This will further depolarize DC, decreasing the spread resistance, etc. This scenario results in an autocatalytic cycle leading to AC corrosion. Getting out of this cycle requires control of the AC current density as well as control of the DC current density, as defined in Section 6.

4.5 According to the present scientific explanation, the mechanism of AC corrosion involves one or more of the following processes:[2-4,6-9]

4.5.1 Lack of passivity due to the fast cycling of the potential across the immune/passive stability line of steel on the Pourbaix diagram. The corrosion process is fast and can occur within the period of an AC cycle, whereas subsequent passivation requires the formation of ferrous oxides or hydroxides. These processes are slower and may not run to completion within the period of an AC cycle.

4.5.2 Cycling of the potential between the regions of stability of protecting and non-protecting ferrous oxides and –hydroxides, the result of which is a net oxidation of the steel.

4.5.3 Extreme alkalization at the coating defect due to the AC corrosion cycle described. The very high pH values at the coating defects, combined with the AC may reach the critical high-pH corrosion area in the Pourbaix diagram, favoring corrosion by the formation of $HFeO_2^-$.

4.5.4 Thermal heating due to the exchange of high AC current densities has been reported to be a potential source for increasing the risk of AC corrosion. Increased soil conductivity and reaction kinetics are generally expected during local soil heating, and bubble formation as well as local soil dry out may occur.

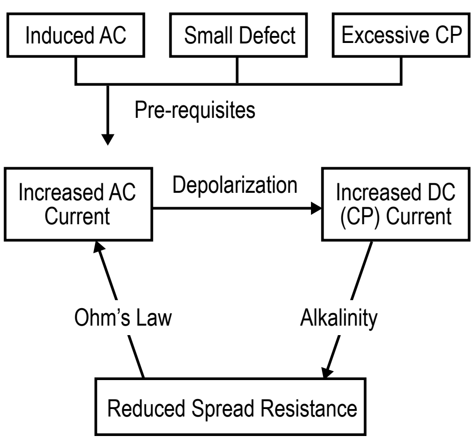

Figure 2: Autocatalytic Nature of AC Corrosion on Cathodically Protected Pipelines

Section 5: Risk Assessment

The risk assessment procedure for AC corrosion is different when dealing with existing pipelines (see Paragraph 5.1), new interference sources (see Paragraph 5.2), or new pipelines (see Paragraph 5.3).

5.1 For existing pipelines, the AC corrosion evaluation process recommends an initial analysis involving factors such as pipeline history record, proximity assessments, CP data and evaluation of existing pipeline and coupon data, etc. If the initial analysis indicates that an AC corrosion risk is present, the initial analysis should be followed by a detailed analysis involving AC calculations and/or AC measurements, evaluation of historical CP data and abnormalities, DC interference, in line inspection results and other existing data relevant for the analysis. If the data available is insufficient for making a reasonable assessment based on sound engineering practices, the existing data material should be supplemented.

5.2 New AC or DC interference sources that may cause additional corrosion risk on existing pipelines shall be subject to detailed analysis. This should be carried out as early as possible, preferably at design stage, and subsequently—when the new source is fully established—practical measurements should be made. Some guidelines are outlined in this section.

5.3 New pipelines with interfering AC systems shall be subject to detailed analysis at the design stage, and subsequently—when established in practice—be subjected to practical measurements. Some guidelines are identified in this section.

5.4 Initial analysis on existing pipelines can be performed in order to gain an initial impression on the risk of AC corrosion or in order to identify if supplementary investigations or analysis are required. The initial analysis may comprise the following:

5.4.1 Pipeline Corrosion History: If previous corrosion incidents—whether in line inspection results or revealed by excavation or leakage—have failed to be explained with certainty using other mechanisms, they could beneficially be re-evaluated in view of AC corrosion characteristics given in this standard.

5.4.2 AC Voltage Measurements: Generally, the risk of AC corrosion increases with increasing AC voltage even though it has been observed that even at low AC voltages (<1V), AC corrosion can occur if the spread resistance and/or bulk soil resistivity is very low. This is, however, an extreme condition. Furthermore, regardless of the AC voltage level, high resistivity soils will generally result in low AC current density and subsequently lower the risk of AC corrosion.

5.4.3 DC Cathodic Protection Potential: AC corrosion may result from the case of inadequate or excessive CP present on a pipeline. If significant pipe metal voltage drops occur due to the pipeline current, it should be considered to further investigate this in combination with the above AC voltage observations.

5.4.4 Soil Resistivity Surveys: The spread resistance is influenced by the soil resistivity. As such, if results from soil resistivity surveys indicate areas with low soil resistivity combined with points described in Paragraphs 5.4.1-5.4.3, initiation of further analysis should be considered. The following soil resistivity parameters can be applied as a guideline to corrosion risk:[10,11]

- Below 25 Ω.m: very high risk,
- Between 25 and 100 Ω.m: high risk,
- Between 100 and 300 Ω.m: medium risk,
- Above 300 Ω.m: low risk.

5.4.5 DC Interference: If there is evidence of cathodic or anodic interference in combination with AC, further detailed analysis shall be considered.

5.4.6 Coupon or Corrosion Rate Probe Measurements: If the criteria (see Section 6) are found to be violated, detailed analysis shall be performed.

5.5 Detailed assessment of the induced AC voltage shall include calculations and/or AC voltage measurement surveys. A CP system design should include an evaluation to estimate the level of AC voltages and currents.

5.5.1 Calculations of the induced AC along the pipeline should be made in accordance with NACE SP0177. The calculations should be used in the establishment of a mitigation design strategy integrating principles stipulated in Section 7.

5.5.2 AC pipe to electrolyte potential measurements shall be conducted over those portions of the interfered pipeline on which AC exposure has been noted or is suspected. The exact location, date and time that each measurement was taken shall be recorded and compared with information (where obtainable) from the electric utility company regarding peak load conditions and actual load conditions at the time of measurement. The AC pipe to electrolyte potential measurements can then be paired with the load information to predict worst case induction level. Datalogging over an extended period is also useful in this regard.

The AC calculation and/or AC pipe to electrolyte potential measurements will result in a detailed knowledge of the induced AC level along the pipeline. The optimum position of AC mitigation measures can be determined by computing tools and/or field measurements—thus forming the (AC) mitigation strategy.

Section 6: Criteria

6.1 Corrosion Rate: Effective control of AC corrosion can be shown by a documented corrosion rate less than 0.025 mm/y (1 mil per year) which is the commonly used benchmark for effective external corrosion control according to NACE SP0169. This can be achieved using weight loss coupons or corrosion rate probes such as electrical resistance type probes. Comparison of consecutive in line metal loss inspection tools may also be used to quantify corrosion, provided the resolution of the applied tool is sufficient to detect small-diameter attacks such as AC corrosion.

6.2 Current Density: Unless effective AC corrosion control has been otherwise documented (Paragraph 6.1), the AC current density should not exceed a time-weighted average of:

- 30 A/m^2 if DC current density exceeds 1 A/m^2
- 100 A/m^2 if DC current density is less than 1 A/m^2

The AC- and DC current densities are measured at coupons according to the guidelines given in Section 8.

6.3 AC Voltage: The AC voltage induced on a pipeline is the driving force for AC corrosion. The AC voltage should be mitigated to a level where the above current densities are met.

6.4 Cathodic Polarization: AC corrosion is inhibited by cathodic polarization. The criteria given in NACE SP0169 shall be followed,[5] but the cathodic DC current densities given in Paragraph 6.2 should be noted.

6.5 The above criteria shall be documented for a representative period of time, accounting for variations in influencing parameters.

Section 7: Mitigation

7.1 AC corrosion can be controlled by mitigating the induced AC voltage (reduce the pipe coating stress voltage), by controlling the pipeline CP condition, and by controlling DC interference. The measures should be taken in parallel.

7.2 AC Mitigation: The AC mitigation can be made in several ways, in accordance with NACE SP0177.[1]

7.3 Control of the Cathodic Protection Condition: Since AC corrosion may result both if inadequate and if excessive CP is applied, the CP system should be designed to maintain a uniform potential profile along the pipeline. If significant pipe metal voltage drops occur due to the pipeline current, it should be considered to increase the number of CP systems attached as well as optimize the position of the CP systems to minimize voltage drops in the pipeline and hence the risk of inadequate or excessive CP.

7.4 Control of DC Interference Currents: Both anodic and cathodic DC interference conditions shall be considered, since AC corrosion may result both if inadequate CP is present during anodic interference, or if excessive CP results from cathodic interference. DC interference should be mitigated in accordance with NACE SP0169.[5]

7.5 Mitigation of AC Corrosion through Construction Design: Especially during the engineering design of new pipelines or new AC high voltage power lines, the possibilities of reducing the induced AC voltage should be considered whenever practical. The magnitude of AC induction depends on several factors as stipulated in NACE SP0177. Also, repair of coating faults mitigates the initiation and propagation of AC corrosion.

7.6 Since AC corrosion can proceed at a very high rate, the mitigation measures planned for new pipelines must be in place as soon as the pipeline is in contact with the soil.

Section 8: Monitoring Strategies

8.1 Locations along the pipeline suitable for AC corrosion tests and monitoring should result from the AC corrosion risk assessment (Section 5). Test points should be installed where the analysis shows a risk of AC corrosion. Such locations include:

a) Locations at which the AC voltage is shown by calculation or by AC voltage surveys to be significant,
b) Locations at which the soil resistivity is low (see Paragraph 5.4.4 for guidance),
c) Locations at which the CP condition can be excessive e.g. nearby CP current sources,
d) Locations at which the CP condition can be inadequate like in mid points between CP current sources,
e) Locations at which DC interference (anodic or cathodic) is present,
f) Locations where in line inspection, excavation activities or leak history have shown corrosion activity,
g) Locations where observations on coupons or soil corrosion probes have exceeded threshold values as defined in Section 6.

8.2 Installation of coupons and/or corrosion rate probes is necessary in order to investigate and monitor the AC corrosion risk at the test stations. The installation of coupons and probes should be made in accordance with NACE SP0104.[12] The capability of the coupon or probe surface to represent an actual coating defect on the pipeline must be maintained to the greatest possible extent. The following points must be considered:

a) The coupon/probe shall be positioned in the same soil or backfill as the pipeline itself.
b) The geometry (size and shape) of the coupon/probe influences the spread resistance. Unlike recommendations for other CP applications where the coupon should simulate the largest anticipated coating defect on the

structure,[12] a 1 cm^2 coupon or probe is generally applied for AC corrosion risk evaluation.[10,11]

c) The coupon/probe should not cause or receive any electrical interference from adjacent coupons or coating faults unless being part of the purpose of monitoring.

d) The coupon/probe should have, and maintain, an effective electrical contact with the surrounding soil. During the installation process, the soil around the coupon shall be compacted to prevent settlement and voids forming around the coupon. These voids could result in loss of full contact between the coupon surface and the surrounding soil, giving inaccurate results.

Coupons and probes can be installed by different methods (during construction, during excavation, by auguring, by hand digging, by vacuum excavation) as described in NACE SP0104.[12]

8.3 Measurements performed at the selected test points shall provide information on the quantities given in Section 6 (Criteria).

8.3.1 Corrosion Rate Measurements

Corrosion rate measurements can, according to NACE SP0104,[12] generally be made using one of the following techniques:

- Electrochemical impedance spectroscopy (EIS)
- Linear polarization resistance (LPR)
- Electrical resistance (ER).

Under cathodic protection and AC interference conditions, the EIS and LPR techniques cannot be applied successfully.

Electrical resistance (ER) measurements require the installation of suitable electrical resistance probes. Corrosion is detected by the increase of the electrical resistance of the coupon as corrosion progressively decreases the thickness of the coupon. The primary advantage is that the average corrosion rate can be followed continuously and used to optimize AC corrosion mitigation measures. The primary disadvantage is that the accuracy is compromised if localized corrosion occurs.

Alternatively, weight loss measurements and visual examination procedures can be applied. This requires installation of pre-weighed coupons. After some time of operation (months/years) the coupon is excavated and brought to a laboratory for cleaning, inspection and weighing. This procedure is described in ASTM[(2)] G1-03.[13] The primary advantage of the procedure is that the visual inspection provides detailed information of the corrosion topography—maximum as well as an average corrosion rate. The primary disadvantage is that the coupon provides no information until it is excavated and that the weight loss measurement does not accurately reflect the corrosion rate if localized corrosion occurs.

8.3.2 Coupon Current Measurements

Coupon currents (AC and DC) can be measured either by the voltage drop across a series resistor or by low resistance ammeters. For both AC and DC current measurements, the value of the series resistor

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

should be sufficiently low to avoid significant disturbance of the system.

For AC current measurements, the value of the series resistor should be insignificant compared with the spread resistance of the coupon. For DC current measurements, the value of the series resistor should be insignificant compared with the sum of the coupon spread resistance and polarization resistance. The accuracy of the measurement depends on the selection of the series resistance value, the accuracy of the series resistor and the accuracy of the meter. The series resistor should be verified regularly, and the meter should be part of routine calibration procedures.

It should be noted that the current densities measured on coupons may not reflect maximum current density if localized corrosion occurs or if cathodic scaling products are unequally precipitating on the surface.

8.3.3 AC Voltage Measurements

AC voltage measurements are used to determine the level of AC interference. For this purpose, measurements must be made using a data logging device programmed to measure the AC voltage in intervals sufficiently short to capture the steady state long-term interference.

AC voltage measurements are usually made with reference to remote earth. However, when continuous anode systems are buried in parallel and close to the pipeline, the coating stress voltage may be a more accurate measure of the driving force for the AC current density than the measure of AC voltage to remote earth.

8.3.4 DC Potential Measurements

When influenced by AC, the accuracy of the DC instruments and data loggers may be significantly affected. Furthermore, AC filters, when provided, may introduce time delays in instant OFF potential readings causing erroneous measurements. To minimize these effects, ON and instant OFF potential measurements are often performed using coupons.

In relation to ON-potential measurements, the advantage of the coupons is limited to the knowledge that an artificial coating defect has been systematically introduced. However, in relation to instant-OFF potentials, disconnecting the coupon from the pipe will remove the coupon from both the AC and DC circuits.

Three different principles can be used individually or simultaneously to measure the DC polarized potentials by minimizing or eliminating the voltage drop on coupons:

1. By inserting a switch in the test station between the pipeline connection and the coupon connection and measuring the potential between the coupon and the reference electrode disconnecting the coupon from the pipeline.
2. By embedding the reference electrode along with the coupon in a test probe. In this case, the voltage drop compensation relies on the geometrical arrangement of the assembly. It is still recommended to test the instant OFF potential in this case for the efficiency of the automated compensation provided by the close distance between the coupon surface and the reference.

3. Quantifying the voltage-drop as the product of the DC current density and the spread resistance of the coupon and subtracting this from the ON-potential value allows the polarized potential to be assessed without disconnecting the coupon from the pipeline. In such a case, the polarized potential can be quantified under the same AC load as experienced by the pipe in normal operation.

Regardless of the technique, due consideration shall be taken about the sources causing uncertainty in the measurement described in Section 4.

8.4 Frequency of Measurements

The frequency of the measurements of the individual parameters shall be selected in accordance with the expected frequency by which said parameter is changing considering the worst case under normal operating conditions of the interfering systems. It must be recognized that AC load will change seasonally as will the physical and chemical environment. AC corrosion is a developing process which has a period of incubation before a critical environment is established. As such, the established measurement protocol shall be maintained for an appropriate extended period of time in order to provide a meaningful judgment of the risk of AC corrosion.

8.5 Accuracy and Operation of Measuring Equipment

The instruments and adopted procedures shall comply with the conditions given in NACE TM0497.[14]

It is a fundamental requirement of any measuring instrument that it shall not cause any unacceptable changes to the circuit being measured. As such, the chosen instrument must be suitable for the specific situation.

The accuracy of the measuring equipment is only one among several factors contributing to the uncertainty of the measurement.

Section 9: Long Term Monitoring

9.1 Monitoring of the AC corrosion shall be regarded as a dynamic process through which the operator becomes increasingly aware of the risks of AC corrosion affecting the pipeline system.

9.2 The monitoring system should be designed to provide information on the AC corrosion criteria outlined in Section 6. Initial locations should be chosen based on the considerations in Paragraph 7.1, and the data evaluation should follow the procedure in Paragraph 8.3.

9.3 In accordance with Figure 1, the monitoring process made at the individual test points can lead to a safe indication per criteria given in Section 6 at the point of measurement, or it can lead to the conclusion that key parameters are exceeded (violated). If key parameters are violated, the information can lead to a renewed risk assessment analysis, or it can lead to a renewed mitigation strategy. Implementations from these renewed analysis or strategies should be tested in practice by further monitoring in an iterative process.

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12. NACE SP0104 (latest revision), "The Use of Coupons for Cathodic Protection Monitoring Applications" (Houston TX: NACE).

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( ) European Committee for Standardization (CEN), Avenue Marnix 17, B-1000 Brussels, Belgium.
(5) International Organization for Standardization (ISO), Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.

Appendix A
Measurement and Monitoring Equipment
(Nonmandatory)

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

Equipment installed on the pipeline, such as coupon test stations or soil corrosion probes, is used to monitor AC current density and corrosion rate on the pipeline at the location of installation. These devices will allow evaluation of existing pipeline and coupon data.

For analytical purposes, this data is required to be measured over time through periodic surveys or data logging. This measured data should be correlated with AC line load currents on the power lines affecting the pipeline together with cathodic protection potentials.

Coupon test station or soil corrosion probes measurements

These measurement devices can assist in determining AC and DC current density values on the pipeline. The AC and DC current density values (criteria) associated with AC corrosion mechanisms are outlined in Section 6.

A documented corrosion rate of less than 0.025 mm/y using weight loss coupons or soil corrosion probes connected to the pipeline at selected points is considered an effective criterion.

In accordance with Section 7, AC corrosion measurement and monitoring techniques and equipment are specified to ensure accurate data recording and monitoring of the corrosion risk.

Some of the testing and monitoring equipment required to determine AC corrosion effects to specific pipeline sections include the following:

- Coupon test stations
- Soil corrosion probes
- Data logging equipment – temporarily installed at a location
- Remote monitoring equipment – permanent /semi-permanent installations
- AC/DC multimeter – with appropriate voltage ranges and adequate input impedance. Commonly used digital instruments have a nominal impedance of 10 megaohms.
- AC/DC ammeter
- Copper-copper sulfate reference electrode
- Permanent reference electrode – installed at coupon test stations
- Soil resistivity measurement equipment

Failure to select and use test instruments correctly can cause errors in these field measurements.

Some of the required parameters for these devices are outlined below:

- Data Logger or Remote Monitoring Equipment – time intervals sufficiently short to capture variations in the system and memory capacity to allow data logging for significant periods of time.

- Coupon current measurement – using the following methods:

  Voltage drop across a series resistor (sufficiently low to avoid disturbance)
  or
  Zero resistance ammeter

All test equipment shall be calibrated regularly in accordance with applicable procedures to assure accuracy of test results.

Accuracy and operation of measuring equipment shall comply with NACE TM0497.[14]

Duration of testing or monitoring could have a major role in deciding the likelihood of AC corrosion attack.

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