FUNDAMENTALS OF CATHODIC PROTECTION

Period 4 & 5

Basic Corrosion Course 2017
Chapter 4
Fundamentals of Cathodic Protection

• Chapter Objectives:
  – Theory
  – Types
  – Use with coated structures
  – Use with electrical isolation
  – Electrical continuity of protected structures
  – Test stations
  – Criteria of protection
Fundamentals of Cathodic Protection

Basic Corrosion Cell

- Anode
- Cathode
- Electrolyte
- Return Circuit (bond, metallic path)
Theory of Cathodic Protection

• Corrosion occurs only at the anode

• If a structure can be made entirely cathodic “it will not corrode”

• Anodes are more negative potential (higher) than cathodes.

• Potential difference between the anode and cathode causes current to flow from the anodes through the electrolyte to the cathode

➢ It is common practice to refer to more negative potentials as being higher than less negative potentials.
Theory of Cathodic Protection

• Polarization — Discussed in Chapter 2

  – Causes the potential of a structure or point on a structure to increase (become more negative).

  – If the cathodes are polarized up to the potential of the anodes, there will be no potential difference between the original anodic and cathodic spots.

  – No potential difference = no current flow
Theory of Cathodic Protection

Polarization

- Ohms Law \( I = \frac{E}{R} \)
  - If \( E \) (potential difference) = 0, then \( I = \frac{0}{R} \), and \( I = 0 \)
Theory of Cathodic Protection
Theory of Cathodic Protection

Distance
Theory of Cathodic Protection

![Graph showing the voltage vs. distance for cathodic protection. The graph has a horizontal line indicating the negative voltage, and the voltage fluctuates above and below this line.](image-url)
Theory of Cathodic Protection
Theory of Cathodic Protection
Theory of Cathodic Protection

Partial Cathodic Protection – Two corroding areas (1&2) still evident.
Theory of Cathodic Protection

- Complete Cathodic Protection –
  - Protective current is flowing to all points on the structure, and the structure has been polarized to a potential higher than any local anodic potential that might be expected.
Types of Cathodic Protection

(2) Systems:

• Galvanic — “sacrificial anodes”

• Impressed Current — “uses an external source of current”

➢ Each has its own advantages and limitations
Galvanic Anode System

• Uses:
  – Small current requirement
  – Generally resistivity < 10,000 OHM CM
  – Coated Services
  – Electrically isolated structures
  – Clearing interferences
Galvanic Anode System

• Advantages:

  – No power required
  – Little maintenance
  – Little chance of interference
  – Ease of installation
Galvanic Anode System

- **Limitations:**
  - No adjustment of outputs except by inserting resistance into the circuit.
  - Replacement difficulty – i.e. streets, paved areas.
  - Limited current output.
  - Small driving voltage – limits use in high resistance soil.
  - Usually limited to electrically isolated structures.
Schematic of Galvanic Anode Cathodic Protection

Anode Connected Directly to Structure

Figure 4-5a
Schematic of Galvanic Anode Cathodic Protection
Anode Connected to Structure Through a Test Station. Figure 4-5b
Typical Galvanic Anode Cathodic Protection

25 feet to 500 feet is typical anode spacing

Figure 4-6
Impressed Current System

• Typical uses:
  – Large amounts of current are needed.
  – Varying amounts of current are needed
  – On bare and coated structures
  – On isolated and non-isolated (shorted) facilities

• Typical applications;
  • Large diameter pipe
  • Cross country pipelines
  • Above ground tank bottoms
  • Compressor stations
Schematic of Impressed Current Cathodic Protection

Power Source Typically a Transformer / Rectifier

Grade

Coated Thermit Weld

(-) Cable to Structure

Anodes - Typically Graphite, High Silicon Cast Iron or Mixed Metal Oxide.

(+) Cable to Anode Ground Bed

Figure 4-7
Impressed Current System

• Advantages

  – Adjustable output.

  – Ease of anode replacement, except for deep anode beds.

  – Large current output available.

  – Automatic control available.
Impressed Current System

• Limitations

  – Need for constant electrical power

  – Electrical installation work is required

  – Rectifier requires regular maintenance and monitoring.

  – May create cathodic interference.
Impressed Current System

Ground Bed Methods

– **Surface Point** – non-congested areas / CC Pipelines
  - 1 location
  - 12’ Deep
  - 100’ to 600’ from structure

– **Surface Distributed** – congested areas
  - Distributed parallel to structure
  - Horizontal current flow

– **Deep Anode** – congested areas, Comp/Reg stations
  - 50’ to 300’ deep
  - Current flows upward
  - Less interference on foreign structures
Surface Point Ground Bed

Set up shown is typical for Transmission Lines

AC power

Rectifier

Buried Header Cable

Anodes
Usually Graphite, High Silicon Cast Iron or Mixed Metal Oxide. Bottom of anodes usually 12 feet below Grade.

Pipe or Structure

100 feet to 600 feet Typical

Impressed Current Cathodic Protection Using Surface Point Groundbed

Figure 4-8
Surface Distributed Ground Bed

Buried Header Cable & Anodes

Rectifier Number 2

Water & Gas Distribution Lines

Rectifier Number 1

20 Inch Bare Gas Main

Impressed Current Cathodic Protection Using Distributed Groundbed

Figure 4-9
Deep Anode Ground Bed

Schematic of Impressed Current Cathodic Protection

Power Source Typically a Transformer / Rectifier

Grade

Protected Structures

50 feet to 300 feet or more

Anode Groundbed

Impressed Current Cathodic Protection Using Deep Anode Groundbed

Protective Current

Figure 4-10
Coatings and Cathodic Protection

- Coatings are the primary line of defense against corrosion.
- Holidays are a major cause for corrosion failure.
- Cathodic protection is an essential supplement to coated pipe.
- Federal and state regulations require cathodic protection on all pipelines and tanks that contain hazardous and other regulated substances.

➢ It is considered poor engineering to install structures without cathodic protection since early leakage at holidays is otherwise certain.
Coatings and Cathodic Protection

• Economic Factors

  – Bare Steel System

    ▪ Requires a sufficient size system to protect entire surface.

    ▪ Uses a large number of galvanic anodes or impressed system.

    ▪ Large investment in cathodic protection
Coatings and Cathodic Protection

• Economic Factors

– Coated Structures

▪ Good coating should be 99% perfect

▪ Allowing for deterioration 95% not unreasonable

▪ Only protecting 5% of the surface
  • Requires smaller and less expensive methods for protection.
  • Reduces potential for stray current

➢ Combined cost of coating and cathodic protection is almost always less than the cost of protecting bare steel structures.
Figure 4-11 illustrates the concept of protecting bare versus coated structures.

(A) Bare Structure

Sufficient Current Must Be Supplied to Protect the Entire Structure

(B) Coated Structure

Only Enough Current Need Be Supplied to Protect the Coating Holidays - Typically 1 to 5% of the Bare Current Requirement
Cathodic Protection

- **Electrical Isolation**
  
  - Easier to control size of area and levels of cathodic protection required.
  
  - Confines the protective current to the desired structure.

  - Multiple isolators helps to limit sections that are impacted by a failed isolator.

  ➢ Wherever isolation fittings are used, it is essential that they not be bypassed or “shorted”.


Typical Isolation

Typical Galvanic Anode Cathodic Protection

25 feet to 500 feet is typical anode spacing

Visual representation of a typical galvanic anode cathodic protection system, including service, anode, protective current, electrical isolation, coated pipe, sectionalizing isolation, and protective current.
Cathodic Protection

• Electrical Continuity

  – Lack of continuity can cause sections to remain unprotected.

  – When impressed current is used, non-continuous parts may incur stray current damage.

  – Many fittings may not provide electrical continuity and may need to be bonded.
**Typical Joint Bonds**

- Bond Cable To Follower Ring On Mechanical Joint
  - Insulated Copper Bond Cable
  - Coated Thermit Weld

- Bond Across Flange or Mechanical Joint

- Bond Across Screw Coupling
  - Insulated Copper Bond Cable
  - Coated Thermit Weld

- Bond Across Compression Coupling

*Figure 4-12*
Typical Groundbed
Typical Groundbed
Typical Groundbed
Typical Groundbed
Typical Groundbed
Typical Groundbed
Cathodic Protection

- **Test Stations**

  - Essential part of a cathodic protection system.

  - Consist of wires attached to the structure and are used to determine the effectiveness of the protection.

  - Used to test the presence and extent of corrosion.

  - Various locations: i.e. valves, risers, service lines.
Test Stations

Figure 4-13
CFR 49 PART 195

• §195.571 What criteria must I use to determine the adequacy of cathodic protection?
• Cathodic protection required by this subpart must comply with one or more of the applicable criteria and other considerations for cathodic protection contained paragraphs 6.2.2, 6.2.3, 6.2.4, 6.2.5 and 6.3 in NACE SP 0169 (incorporated by reference, see §195.3).

• §195.573 What must I do to monitor external corrosion control?
• (a) Protected pipelines. You must do the following to determine whether cathodic protection required by this subpart complies with §195.571:
  • (1) Conduct tests on the protected pipeline at least once each calendar year, but with intervals not exceeding 15 months. However, if tests at those intervals are impractical for separately protected short sections of bare or ineffectively coated pipelines, testing may be done at least once every 3 calendar years, but with intervals not exceeding 39 months.
  • (2) Identify not more than 2 years after cathodic protection is installed, the circumstances in which a close-interval survey or comparable technology is practicable and necessary to accomplish the objectives of paragraph 10.1.1.3 of NACE SP 0169 (incorporated by reference, see §195.3).
Appendix D to Part 192—Criteria for Cathodic Protection and Determination of Measurements

I. Criteria for cathodic protection—A. Steel, cast iron, and ductile iron structures.

1. A negative (cathodic) voltage of at least 0.85 volt, with reference to a saturated copper-copper sulfate half cell. Determination of this voltage must be made with the protective current applied, and in accordance with sections II and IV of this appendix.

2. A negative (cathodic) voltage shift of at least 300 millivolts. Determination of this voltage shift must be made with the protective current applied, and in accordance with sections II and IV of this appendix. This criterion of voltage shift applies to structures not in contact with metals of different anodic potentials.

3. A minimum negative (cathodic) polarization voltage shift of 100 millivolts. This polarization voltage shift must be determined in accordance with sections III and IV of this appendix.

4. A voltage at least as negative (cathodic) as that originally established at the beginning of the Tafel segment of the E-log-I curve. This voltage must be measured in accordance with section IV of this appendix.

5. A net protective current from the electrolyte into the structure surface as measured by an earth current technique applied at predetermined current discharge (anodic) points of the structure.
II. Interpretation of voltage measurement. Voltage (IR) drops other than those across the structure-electrolyte boundary must be considered for valid interpretation of the voltage measurement in paragraphs A(1) and (2) and paragraph B(1) of section I of this appendix.

IV. Reference half cells. A. Except as provided in paragraphs B and C of this section, negative (cathodic) voltage must be measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte.
NPRM (REDLINE)

- **Appendix D to Part 192 – Criteria for Cathodic Protection and Determination Measurements**
- **Criteria for cathodic protection**—
- **Steel, cast iron, and ductile iron structures.**
  - A negative (cathodic) voltage across the structure electrolyte boundary of at least 0.85 volt, with reference to a saturated copper-copper sulfate reference electrode, often referred to as a half cell. Determination of this voltage must be made with the protective current applied, and in accordance with sections II and IV of this appendix.
  - A minimum negative (cathodic) polarization voltage shift of at least 300 100 millivolts. This polarization voltage shift must be determined with the protective current applied, and in accordance with sections II and IV of this appendix. This criterion of voltage shift applies to structures not in contact with metals of different anodic potentials.
  - A minimum negative (cathodic) polarization voltage shift of 100 millivolts. This polarization voltage shift must be determined in accordance with sections III and IV of this appendix.
  - A voltage at least as negative (cathodic) as that originally established at the beginning of the Tafel segment of the E-log-I curve. This voltage must be measured in accordance with section IV of this appendix.
  - A net protective current from the electrolyte into the structure surface as measured by an earth current technique applied at predetermined current discharge (anodic) points of the structure.
Appendix D to Part 192 – Criteria for Cathodic Protection and Determination Measurements

II. Interpretation of voltage measurement. Structure-to-electrolyte potential measurements must be made utilizing measurement techniques that will minimize voltage (IR) drops other than those across the structure-electrolyte boundary. All voltage (IR) drops other than those across the structure-electrolyte boundary will be differentiated, such that the resulting measurement accurately reflects the structure-to-electrolyte potential.

III. Determination of polarization voltage shift. The polarization voltage shift must be determined by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift occurs often referred to as an instant off potential. The voltage reading after the immediate shift must be used as the base reading from which to measure polarization decay in paragraphs A(2), B(1), and C of section I of this appendix.
6.2.2 Steel and Cast Iron Piping

6.2.2.1 External corrosion control can be achieved at various levels of cathodic polarization depending on the environmental conditions. However, in the absence of specific data that demonstrate that adequate CP has been achieved, one or more of the following shall apply:

6.2.2.1.1 A negative (cathodic) potential of at least 850 mV with the CP applied. This potential is measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte. Voltage drops other than those across the structure-to-electrolyte boundary must be considered for valid interpretation of this voltage measurement.
NOTE: Consideration is understood to mean the application of sound engineering practice in determining the significance of voltage drops by methods such as:

- 6.2.2.1.1.1 Measuring or calculating the voltage drop(s);
- 6.2.2.1.1.2 Reviewing the historical performance of the CP system;
- 6.2.2.1.1.3 Evaluating the physical and electrical characteristics of the pipe and its environment; and
- 6.2.2.1.1.4 Determining whether or not there is physical evidence of corrosion.

- 6.2.2.1.2 A negative polarized potential (see definition in Section 2) of at least 850 mV relative to a saturated copper/copper sulfate reference electrode.
- 6.2.2.1.3 A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion.
6.2.2.1.2 A negative polarized potential (see definition in Section 2) of at least 850 mV relative to a saturated copper/copper sulfate reference electrode.

6.2.2.1.3 A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion.

6.2.2.2 Special Conditions

6.2.2.2.1 On bare or ineffectively coated pipelines when long-line corrosion activity is of primary concern, the measurement of a net protective current at predetermined current discharge points from the electrolyte to the pipe surface, as measured by an earth current technique, may be sufficient.
6.2 Criteria

6.2.1 Criteria for Steel and Gray or Ductile Cast-Iron Piping

6.2.1.1 Criteria that have been documented through empirical evidence to indicate corrosion control effectiveness on specific piping systems may be used on those piping systems or others with the same characteristics.

6.2.1.2 A minimum of 100 mV of cathodic polarization. Either the formation or the decay of polarization must be measured to satisfy this criterion.

6.2.1.3 A structure-to-electrolyte potential of –850 mV or more negative as measured with respect to a saturated copper/copper sulfate (CSE) reference electrode. This potential may be either a direct measurement of the polarized potential or a current-applied potential. Interpretation of a current-applied measurement requires consideration of the significance of voltage drops in the earth and metallic paths.
SUMMARY

Criteria

- Pipe-to-Soil Potential of at least -0.850 volts with respect to a copper-copper sulfate reference electrode.
  - Measured with cathodic protection ON
    - Must consider IR drop
  - Measured with cathodic protection OFF

- 100 mV (0.100 Volts) Polarization
Compliance Criteria
Compliance Criteria
Compliance Criteria
Compliance Criteria
Compliance Criteria
Compliance Criteria
Compliance Criteria
Compliance Criteria
Compliance Criteria
Compliance Criteria

![Graph showing voltage over time with a drop of 100 mV]
SUMMARY

Criteria

• Pipe-to-Soil Potential of at least -0.850 volts with respect to a copper-copper sulfate reference electrode.
  – Measured with cathodic protection ON
    • Must consider IR drop
  – Measured with cathodic protection OFF

• 100 mV (0.100 Volts) Polarization
Questions?

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