Control of DC and AC Interference on Pipelines

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CORROSION
AND
CATHODIC PROTECTION
**Basic Corrosion Mechanism**

In typical soils, at **Cathode**:  
Electrons consumed by water/oxygen – protective film forms

Corrosion Current  
(Conventional Current Flow)

In typical soils, at **Anode**:  
Iron goes into solution and combines with ions in the electrolyte to form corrosion Deposits

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**Metallic Path**

**Cathode (protected)**

**Electrolyte**  
(water, soil, mud, etc.)

**Anode (corrodes)**

**Corrosion Deposits**
Basic Cathodic Protection Mechanism

Metallic Path

Electrolyte
(water, soil, mud, etc.)

Anode
(corrodes)

Cathodes
(protected)

Copper

Magnesium

Steel
Cathodic Protection is the application of protective current from anodes onto the pipeline, forcing the pipeline to become cathodic.
Cathodic Protection – Impressed Current System

- Cathodic Protection Current from Anode Groundbed
- Rectifier
- Pipeline
- Cathodic Protection Anode Groundbed
Basic Pipe-to-Soil Potential Measurement

Copper-Copper Sulfate Reference Electrode

Polarization film

Pipeline

High Impedance Voltmeter (Miller LC-4 Pictured)

Area of Pipe detected by electrode

- 1.150 V DC
DC STRAY CURRENT INTERFERENCE
**DC Stray Current Interference**

- Stray current interference occurs when DC current travels along a non-intended path.
- Where DC stray current is received by a structure, the area becomes cathodic and generally, no corrosion occurs.
- Where DC stray current exits the structure to return to its source, corrosion occurs and depending on magnitude of stray current, can lead to accelerated corrosion failures.
Using Faraday’s Law, weight loss is directly proportional to current discharge and time ... Steel is consumed at ~21 lbs/amp-year

**Example:** A 1-inch diameter cone shaped pit in 0.500” thick steel would weighs 0.04 pounds.

One ampere of DC current discharging from a 1-inch diameter coating holiday would cause a through wall, cone shaped pit to occur in 0.0019 years or 16 hours.

Stray current corrosion can be a serious problem.
Sources of DC Stray Currents

**Static DC Currents:**
- Foreign Cathodic Protection Systems

**Dynamic DC Currents:**
- DC Traction Power Systems: Transit, People Movers, Mining Transport Systems
- HVDC: Imbalance, Monopolar Earth Return
- Welding Equipment with Improper Ground
- Geomagnetic (Telluric) Earth Currents
Corrosion Caused by Stray Current

Foreign Pipeline

Area of Current Discharge – ANODIC

Company Pipeline

Rectifier

Anode Bed

Area of Current Pickup – Cathodic
Potential measurements (Close Interval Surveys) are typically used to identify stray current areas.

Current Pickup

- Pipe-to-Soil Potential

Current Discharged
Back to Source – Metal

Loss (if Polarized Potential more negative than -850 mV, controlling reaction is the Oxidation of OH⁻; no metal loss)

Line Being Interfered With

Line Causing Interference
Mitigation of DC Stray Current

There are several methods to control/eliminate DC stray currents:

1. Eliminate the source, if possible
2. Bond (direct bond or resistance bond)
3. Recoating
4. Shields
5. Drain sacrificial anodes
Mitigation of DC Stray Current - Direct Bond

- Meter Reads: - 42 mV
- Bond Current: \( \frac{42}{0.01} = 4200 \text{ mA or 4.2A} \)
- Direction of Current? (polarity)
- Is this a Critical Bond???
Mitigation of DC Stray Current - Resistance Bond

- Meter Reads - 3 mV
- Slide Resistor at 2 ohm
- Bond Current = 3/2 = 1.5 mA or 0.0015 A
- With Direct Bond 4.2 A, with Resistance Bond 0.0015A (must verify potential at crossing)
Mitigation of DC Stray Current - Recoating

The application of the coating increases the resistance between the two pipelines, resulting in large reduction (and possibly elimination) of the Discharge Stray Current.
The application of a non-conductive shield increases the resistance between the two pipelines, resulting in a large reduction (and possibly elimination) of stray current.
The sacrificial anodes are installed to allow for a very low resistance path between the two pipelines, forcing the stray DC currents to discharge from the anodes (instead of the pipeline). Proper design of these anodes (number, size) is critical.
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AC STRAY CURRENT INTERFERENCE
AC Interference

High Voltage AC Power Lines Can Cause:

1. AC Corrosion of The Steel
2. Personnel Shock Hazard Due To Induced AC Voltages
AC Corrosion

AC current can cause corrosion of the steel pipeline.

Courtesy NACE
Based on recent studies of AC corrosion related failures, the following guideline was developed:

- AC induced corrosion does not occur at AC current densities less than 20 A/m²; (~ 1.86 A/ft²)
- AC corrosion is unpredictable for AC current densities between 20 to 100 A/m²; (~ 1.86 A/ft² to 9.3 A/ft²)
- AC corrosion typically occurs at AC current densities greater than 100 A/m²; (~9.3 A/ft²)
- Highest corrosion rates occur at coating defects with surface areas between 1 and 3 cm² (0.16 in² – 0.47 in²)
**AC Induced Current Calculation**

\[ i_{ac} = \frac{8V_{ac}}{\rho \pi d} \]

- \( i_{ac} \) – AC current density (A/m\(^2\))
- \( V_{ac} \) – AC Volts (V)
- \( \rho \) – Soil resistivity (Ω–m)
- \( d \) – holiday diameter (m)

**Example:**

A holiday area of 1.5 cm\(^2\), with an induced voltage of 5.4 V would produce an AC Current Density of 100 A/m\(^2\) in 1000 ohm-cm soil.

**Figure 3-55:** AC Voltage Required to Produce 100 A/m\(^2\) Current Density for a Variety of Holiday Sizes and Soil Resistivities
AC Interference

- A more frequent consideration as right-of-ways become more difficult to obtain.
- The electromagnetic field created by AC power changes 120 times per second.
- Metallic structures subject to a changing electromagnetic field will exhibit an induced voltage (hence induced AC current).
- Phase to ground faults can expose an underground structure to very high AC currents
AC Interference

The magnetic field generated by the overhead power lines induces an AC voltage onto the pipeline (which creates AC currents). The magnitude of such currents depend on many factors such as coating condition, soil composition, power line voltage, distance, etc.
**AC Interference**

*Electrostatic (Capacitive) Coupling*

- Aboveground Structures Only
  
  (such as an above ground test station, a car, or pipe stored near ditch)

*Electromagnetic (Inductive) Coupling*

- Structure Acts As Secondary Coil
- Structure Above Or Below Ground
  
  (most important component, causes AC corrosion of steel as well as personnel hazard potential)

*Conductive (Resistive) Coupling*

- Buried Structures Only (during line faults)
AC Interference – Computer Modeling

Conditions Modeled:
- Steady State Induced AC Levels
- Pipe Potentials Under Phase-to-Ground Fault
- Potentials to Remote Earth
- Step Potentials
- Touch Potentials

- 15 volt Limitation for Protection of Personnel
- 1000 volts - 3000 volts Causes Coating Damage
- >5000 volts Can Cause Pipe Structural Damage
AC Interference – Mitigation Measures

- Separate Structure and AC Line
- Use Dead Front Test Stations (to eliminate shock hazard)
- Install Polarization Cells to Ground (grounding)
- Install Semiconductor Devices to Ground (grounding)
- Use Bare Steel Casings or anode beds as Grounds with DC Decoupling devices (capacitors, polarization cells)
- Install Equipotential Ground Mats at valves, test stations (for shock hazard)
- Use Sacrificial Anode and paralleling zinc ribbon or Copper wire as Ground Electrodes (normally with decoupling devices)
Codes and Standards

- EPRI/AGA “Mutual Design Considerations for Overhead AC transmission Lines and Gas Pipelines”

- NACE RP 0177 “Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems”

- Canadian Electrical Code C22.3 No. 6-M1987 “Principles and Practices of Electrical Coordination between Pipelines and Electric Supply Lines”
Dead Front Test Station (Personnel Protection)

Insulated Test Posts
Polarization (Kirk) Cell - Grounding

<table>
<thead>
<tr>
<th>Model</th>
<th>Rated Capacity for 0.5 seconds (amps)</th>
<th>Steady State Rating (amps)</th>
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<td>K-5A</td>
<td>5,000</td>
<td>30</td>
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<tr>
<td>K-25</td>
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<td>175</td>
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<tr>
<td>K-50</td>
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<td>350</td>
</tr>
</tbody>
</table>
Semiconductor Decoupling Devices - Grounding

SSD – Solid State Decoupler

PCR – Polarization Cell Replacement

Courtesy of Dairyland
Examples of De-Coupling Devices - Rating

**Polarization Cell Replacement (PCR)**
- 60 Hz Fault Current @ 1 cycle: 6,500; 20,000; 35,000 A  
  @ 3 cycles: 5,000; 15,000; 27,000 A  
- Lightning Surge Current @ 8 X 20 μseconds: 100,000 A  
- Steady State Current Rating: 45 or 80 amps AC

**Solid State Decoupler (SSD)**
- 60 Hz Fault Current @ 1 cycle: 2,100; 5,300; 6,500; 8,800 A  
  @ 3 cycles: 1,600; 4,500; 5,000; 6,800 A  
- Lightning Surge Current @ 4 X 10 µseconds: 100,000A ; 75,000 A  
- Steady State Current Rating: 45 amps AC
Zinc Ribbon Installation for AC Mitigation - Grounding
Equipotential Ground Mat - Used to Protect Personnel from Electric Shock (at test stations, valves, etc.)
Mitigation of AC Interference Using Distributed Galvanic Anodes

Overhead HVAC Transmission Line

Underground Pipeline

Distributed Sacrificial Anodes

Induced Voltage

Without Anodes

With Anodes

Distance
Testing the Effectiveness of AC Mitigation:

- AC pipe-to-soil potential (at test stations and above ground appurtenances) to test for shock hazard voltage
- A CIS (both VDC and VAC) to test the effectiveness of the cathodic protection system as well as the AC potentials on the line. (ON/OFF, the use of decouplers is critical to collect OFF potentials)
- Soil resistivity measurements at high VAC locations
- Calculation of IAC to determine risk of AC corrosion
- Additional localized mitigation measures if needed
THE END

Thank You!

Questions?