GALVANIC ANODE CP DESIGN
PART II
Simplified Design Example

Period #7

Advanced Corrosion Course
2017

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NACE CP-III course design example, courtesy of NACE International

4.9.1(b) Example No. 2

The pipe to be protected is 2,000 feet of 4-in. ID steel (OD = 4.500 in. = 11.43 cm). It is coated and the coating is 98.5% effective. The pipe is electrically isolated and the estimated current requirement is 2 mA/ft² (21.54 mA/m²) of exposed metal. Soil resistivity is 3,500 Ω-cm. Assume the desired pipe-to-soil polarized potential = −1.00 V_{cse}. Life of CP system must be 20 years. Assume pipe resistance is negligible and the CP system utilization factor is 0.85.

General steps:
- Determine current required
- Start with an anode size
- Calculate resistance to ground of one anode
- Determine the current output of one anode
- Determine the number of high potential magnesium anodes required based on the current required
- Determine the life of the anodes. Determine the weight of anode material needed based on the desired life.
- Determine number of anodes required and locations

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CP 3—Cathodic Protection Technologist
July 2007
STEP #1  COLLECT DESIGN DATA

(data from previous page)

• Structure size? *4.500-inches outside diameter x 2,000-feet long*

• Structure coating efficiency? *98.5% = 1.5% bare or damaged*

• Current required to protect one ft\(^2\) of bare structure? *2mA/ft\(^2\)*

• Electrolyte (\(\rho\)) resistivity? *\(\rho = 3,500\Omega/cm\)*

• Required structure polarized potential? *-1.000 V*

• CP system design life? *20-years*

• CP anode chosen?
**STEP #2: CALCULATE STRUCTURE SURFACE AREA**

Need to calculate total surface area of structure, in square feet (ft²)

For a “tubular” structure (pipe): $\pi \times d \times L$

**All measurements must be in FEET! Either multiply inches by 0.0833 or divide inches by 12**

$\pi = 3.14$

$d =$ outside diameter of pipe, in feet (4.5 in $\div 12$ in) $= 0.375$ ft

$L =$ length of pipe, in feet $= 2000$ ft

**Total Surface Area of Structure:** $(3.14 \times 0.375 \text{ ft} \times 2000 \text{ ft}) = 2356 \text{ ft}^2$
**STEP #3: CALCULATE STRUCTURE SURFACE AREA TO PROTECT**

**If coating is 98.5% effective, then 1.5% of pipeline’s total surface area is considered bare and in need of cathodic protection**

100% - 98.5% = 1.5% bare  
Convert percent to a decimal (1.5% ÷ 100) = 0.015

**Structure surface area to protect:** (0.015  x  2356 ft²) = **35.34 ft² bare**

**Note:** A “Fall-of-Potential” (three-pin) resistance test is the only test method to determine actual coating efficiency on an existing buried structure or one with existing galvanic anodes.

**STEP #4: CALCULATE TOTAL CP CURRENT REQUIRED**

Multiply “Surface Area to Protect” by estimated CP current required to protect one square foot of bare structure; 2 ma/ft².

**Current required for protection:** (35.34 ft²  x  2 ma/ft²) = 70.69 or **71ma**
STEP #5: **USE CORRECT ANODE RESISTANCE CALCULATION**

- From information provided on page #2, a designer should be able to conclude the structure to be protected is of small diameter and very well coated. Furthermore, required protective current, 71ma (0.071A), is very small. Electrolyte resistivity, 3,500 Ω/cm, poses minor anode to soil contact resistance issues. Two to four 17-lb Mg anodes should be able to protect the structure. If more than one galvanic anode is required, the anodes would normally be equally spaced along the structure to prevent circuit “attenuation” issues. For this design, spacing would place each anode outside the “area of influence” of the other anodes.

- Anytime an anode is within another anode’s area of influence, it must be treated as a “multiple anode” system and a “paralleling” factor included in the anode resistance calculation. The designer must use the correct resistance calculation for “multiple” and “single” vertical or horizontal anode designs. This statement holds true for either galvanic or impressed current anodes!

- It is always assumed a galvanic anode will be placed 8-ft to 10-ft from the structure. Shorter distances will effect the anode resistance calculation.
TYPICAL ANODE RESISTANCE CALCULATIONS

Single vertical anode

\[ R_v = \left( \frac{0.00521 \cdot \rho}{L} \right) \cdot \left[ \ln \left( \frac{8 \cdot L}{d} \right) - 1 \right] \]

Single horizontal anode

\[ R_h = \left( \frac{0.00521 \cdot \rho}{L} \right) \cdot \left[ \ln \left( \frac{(4 \cdot L^2) + (4 \cdot L) \cdot \sqrt{S^2 + L^2}}{d \cdot S} \right) + \left( \frac{S}{L} \right) - \left( \frac{\sqrt{S^2 + L^2}}{L} \right) - 1 \right] \]

Multiple vertical anodes

\[ R_{mv} = \left( \frac{0.00521 \cdot \rho}{N \cdot L} \right) \cdot \left[ \ln \left( \frac{8 \cdot L}{d} \right) - 1 + \left( \frac{2 \cdot L}{S} \right) \cdot \left( \ln (0.656 \cdot N) \right) \right] \]

***These are three examples of numerous anode bed resistance calculations used for a variety of CP designs***
STEP #6 ACCOMPLISH ANODE RESISTANCE CALCULATION

(For this exercise use dimensions of a 17-lb DNV High Potential Anode. Mg anode specifications are attached to the back of this hand-out. All anode dimensions must be in “feet”.)

Single vertical anode

\[ R_v = \left( \frac{0.00521 \times \rho}{L} \right) \times \left[ \ln \left( \frac{8 \times L}{d} \right) - 1 \right] \]

\[ R_v = \left( \frac{0.00521 \times 3,500}{2.833} \right) \times \left[ \ln \left( \frac{8 \times 2.833}{0.625} \right) - 1 \right] \]

\[ R_v = \left( \frac{18.235}{2.833} \right) \times \left[ \ln \left( \frac{22.664}{0.625} \right) - 1 \right] \]

\[ R_v = 6.437 \times \left[ (\ln 36.262) - 1 \right] \]

\[ R_v = 6.437 \times [3.591 - 1] \]

\[ R_v = 6.437 \times 2.591 = 16.677\Omega \]

\( \rho = \) electrolyte resistivity (3,500\( \Omega \)/cm)

\( d = \) anode “bag” diameter

\( L = \) anode “bag” length
STEP #7 CALCULATE ANODE LEAD WIRE RESISTANCE

• Industry standard for “bag” type galv. anode lead wires; 10-feet of insulated #12-AWG solid copper wire.

• Use attached DC resistance table to find resistance of 1,000-feet of #12 “insulated” copper wire @ 20°C (68°F).

\[
RWIRE = \left( \frac{1.62 \, \Omega}{1000 \, \text{ft}} \right) \times 10-\text{ft} = 0.016\Omega
\]

• Note: 0.016Ω is almost negligible in regards to total circuit resistance. Some designs might require all anodes be installed in just one location because of varying levels of electrolyte resistivity or space restrictions. This might require connecting all anodes to a common header cable, such as is accomplished in a standard impressed current design. These types of situations would increase total cable length to more than 10-feet with corresponding increases in resistance. (25-ft anode spacing for four anodes spaced 25-ft from pipe = 0.162Ω.) It is always best to calculate anode (and structure) wiring resistance to avoid any design mistakes!
STEP #8 : **CALCULATE STRUCTURE RESISTANCE**

STEP #8a : **CALCULATE STRUCTURE RESISTANCE FOR BARE BURIED PIPELINE**

- The H.B. Dwight’s horizontal resistance formula is the appropriate for this case resistance:

\[
\frac{0.00521*\rho}{L} = \left[ \ln \left( \frac{4*L^2 + (4*L)*\left(\sqrt{S^2 + L^2}\right)}{d*S} \right) + \frac{S}{L} - \frac{\left(\sqrt{S^2 + L^2}\right)}{L} - 1 \right]
\]

\[S = \text{structure depth}\]

\[
\frac{0.00521*3500}{2000} = \left[ \ln \left( \frac{4*2000^2 + (4*2000)*\left(\sqrt{3^2 + 2000^2}\right)}{0.375*3} \right) + \frac{3}{2000} - \frac{\left(\sqrt{3^2 + 2000^2}\right)}{2000} - 1 \right]
\]

\[R_s = 0.209\Omega\]
**STEP #8 : CALCULATE STRUCTURE RESISTANCE**

**STEP #8B : CALCULATE STRUCTURE RESISTANCE FOR COATED BURIED PIPELINE**  
*(TAKEN FROM NACE CP LEVEL III PARAGRAPH 4.4.5)*

For any pipe, the potential shift ($\Delta V$) that occurs between the pipe and a reference placed at remote earth, with a test current interrupted can be used in Ohm’s law to calculate the pipe resistance ($R_{pipe}$) as follow:

$$R_s := \frac{V_{on} - V_{off}}{I_t}$$

Where:

- $V_{on}$: Is the pipe to remote earth On potential (with source of current On) in volts.
- $V_{off}$: Is the pipe to remote earth Off (with source of current interrupted) potential in volts.
- $I_t$: Is the test current applied.
- $R_s$: is the pipe resistance to remote earth in $\Omega$. This is the resistance value that should be used to calculate the total circuit resistance in the design of a cathodic protection system.
STEP #8: **CALCULATE STRUCTURE RESISTANCE**

STEP #8B: **CALCULATE STRUCTURE RESISTANCE FOR COATED BURIED PIPELINE**
(TAKEN FROM NACE CP LEVEL III PARAGRAPH 4.4.5)

In this example suppose that a 12 volts car battery with a provisional groundbed was used to measure the pipe to remote earth resistances, providing the following results:

\[
V_{on} := 1.2\text{volt} \quad V_{off} := 1.1\text{volt} \quad I_t := 0.5\text{amp} \\
R_s := \frac{V_{on} - V_{off}}{I_t} \quad R_s = 0.2\Omega
\]
STEP #9: CALCULATE DIFFERENTIAL VOLTAGE OF CIRCUIT

Calculate “differential” voltage ($\Delta E$) between High Pot. Mg anode potential ($V$) and required structure polarization potential ($V$). You must include the voltage consumed by the magnesium sacrificial anode in self polarization: 100 mV.

$$\Delta E = \text{Anode Potential} - 100\text{mv Anode Self-Polarization Voltage} - \text{Structure Potential}$$

$$\Delta E = (-)1.75 - 0.100 - (-)1.00 = -0.650$$

STEP #10: CALCULATE TOTAL CIRCUIT RESISTANCE:

$$R_t = R_a + R_w + R_s$$

$$R_t = R_a (16.677\Omega \text{ Mg anode}) + R_w (0.016\Omega \text{ anode wire}) + R_s (0.2\Omega \text{ structure})$$

$$R_t = 16.72\Omega$$
STEP #11: USING “OHM’S LAW, CALCULATE OUTPUT FOR SINGLE ANODE

- Using “Ohm’s Law”, calculate current output (amps) of a single anode: \( I_a = \frac{\Delta E}{Rt} \)

\[
I_a = \frac{0.650}{16.72} = 0.0385\text{A} \quad \text{or} \quad 39\text{ma} \quad \text{(for one 17-lb Mg anode)}
\]

STEP #11b: D. A. TEFANKJIAN SIMPLIFIED GALVANIC ANODE CALCULATION

- The following simplified equations can be used to determine galvanic anode outputs:

  Bare or poorly coated structure; for Magnesium: \( I_a = \frac{150000 \times f \times y}{\rho} \)

  Good coating; for Magnesium: \( I_a = \frac{120000 \times f \times y}{\rho} \)

  Bare or poorly coated structure; for Zinc: \( I_a = \frac{50000 \times f \times y}{\rho} \)

  Good coating; for Zinc \( I_a = \frac{40000 \times f \times y}{\rho} \)
STEP #12: CALCULATE # ANODES TO MEET CURRENT REQUIREMENT

Number of anodes needed = \( \frac{I_p \text{ (require for protection)}}{I_a \text{ (output per anode)}} \)

Number of anodes needed = \( \frac{71 \text{ ma (require for protection)}}{39 \text{ ma (output per anode)}} \) = 1.82 anodes

(Tefankjian calculation = \( \frac{71 \text{ ma}}{37 \text{ ma}} \) = 1.92 anodes)

Minimum required 17-lb Hi Pot. Mg anodes = 2 each to meet current requirement
STEP #13: CALCULATE ANODE SYSTEM DESIGN LIFE

\[ L = \frac{W \times Ca \times Uf \times E}{Ia} \]

- \( L \) = Estimated life of anode
- \( W \) = Weight of anode = 17 lb
- \( Ca \) = Capacity of Magnesium = 0.114 amp-hr/lb  
  \((Capacity of Zinc = 0.0424 \text{ amp-hr/lb})\)
  
  \((These \ constants \ are \ calculated \ by \ dividing \ theoretical \ amp/hrs \ per \ pound, \ by \ the \ number \ of \ hours \ in \ a \ year)\)
- \( Uf \) = Utilization factor = .85 (anode will require replacement at 85% consumption)
- \( E \) = Anode efficiency = .50 (50% of the anode weight expended protecting pipe)
- \( Ia \) = Anode current output in AMPS = .039A (convert ma to amps)

\[ L = \frac{17lb \times 0.114 \times 0.85 \times 0.50}{0.0389 \text{ amp}} = 21.17 \text{ Years} \]
STEP #14: ANODE INSTALLATION SPACING

- Galvanic anodes are normally spaced at equal distances along a pipeline, taking into account the pipe coating efficiency, soil resistivity and pipe right of way (ROW) availability.
- In this example, and because the pipe has a good coating. (Calculation of pipe potential to remote earth attenuation is not part of the scope of this course)
- Pipeline length = 2000-ft.

\[
2000 \div 4 = 500\text{-ft}.
\]

Space the two anodes 500 feet from each end. This will place them 500-ft from the pipeline center.

__________500-ft__________________500-ft__________
Summary:

• Design calculations for isolated, well coated structures are easier to accomplish than design calculations for existing structures with degraded coatings.

• Design calculations for structures with depleted galvanic anodes should include accurate “current requirement” data, collected in the field by “knowledgeable” persons.

• **Electrolyte testing data is the single most importance data collected for any Cathodic Protection design.**

• Accurate anode and structure resistance data will become important as electrolyte resistivity increases beyond 6,000 Ω*cm.

• Magnesium anodes should always be “driven” near maximum current density to achieve a 50% utilization rating. To achieve this, Mg anodes should be driven at or above a constant current density of 30ma/ft² of anode surface.
Magnesium SuperMAG™
High Potential Anodes

Galvotec Alloys produces High Potential anodes under our trademark SuperMAG™. Chemical analysis and potential tests are performed on every heat.

<table>
<thead>
<tr>
<th>PRODUCT NO.</th>
<th>MODEL NO.</th>
<th>Weight (lbs.)</th>
<th>Anode Dimensions</th>
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Other shapes, sizes and weights available on request.

Typical Electrochemical Properties

- Amps/Thrs/Lb.: 500-550
- Efficiency: 50-58%
- Closed Circuit Potential: -1.50 to -1.75v
- Open Circuit Potential: -1.70 to -1.78v

For the very best in Magnesium Anodes – specify SuperMAG™.

NOTE: While statements contained herein are believed to be accurate, they are offered as suggestions only and no warranty or representation is intended. Galvotec Alloys products are sold subject to the terms and conditions appearing on our printed order acknowledgment.
Using anode shape and driving factor table attached to handout, calculate current output of a single 17-lb HP Mg anode using Tefankjian’s calculation for a structure with a good coating:

$$I_a = \frac{120000 \times f \times y}{\rho}$$
# General Conductor Information

## Dc Resistance

**Resistance in Ohms per 1000 feet per conductor at 20°C and 25°C of solid wire and class B concentric stranded copper and aluminum conductor**

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