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Cathodic Protection

Course Number: EE-02-802

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Module 1: Introduction to Cathodic Protection

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the electrochemical components of a corrosion cell.
- **Evaluate** the functional differences between galvanic and impressed current protection systems.
- **Select** appropriate anode materials based on system design requirements.

Executive Summary: Cathodic protection is a critical engineering method used to mitigate corrosion on metallic structures by minimizing potential differences between anodes and cathodes. By applying external current—either through sacrificial galvanic anodes or regulated impressed current rectifiers—the entire structure is maintained at a single potential, effectively neutralizing active corrosion cells.

Purpose

This manual provides specialized design guidance for **cathodic protection systems**. These systems are essential for maintaining the structural integrity of diverse infrastructure, including **pipelines, underground storage tanks, locks, and ship hulls**.

References

Designers must adhere to established standards from both government and nongovernment bodies to ensure compliance and safety.

Government Publications

- **Department of Transportation:** Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards, Subpart 1.

Nongovernment Publications

- **NACE Standard RP-01-69:** Control of External Corrosion on Underground or Submerged Metallic Piping Systems.
- **NACE Standard RP-02-72:** Direct Calculation of Economic Appraisals of Corrosion Control Measures.

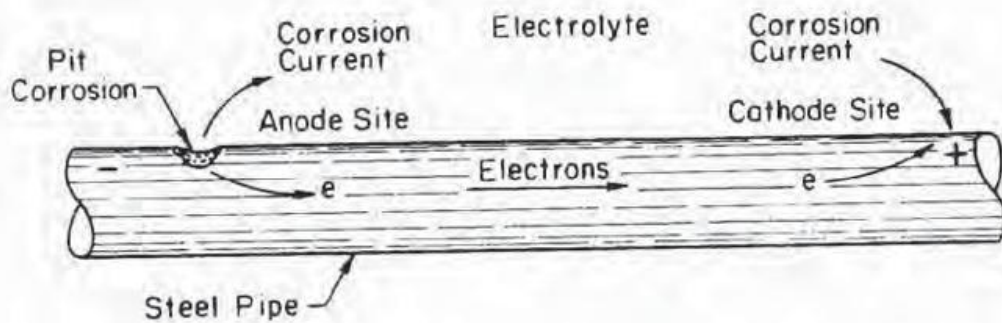
Corrosion Fundamentals

Corrosion is an **electrochemical process** where electrical current leaves a structure at an **anode site**, travels through an electrolyte, and reenters the structure at a **cathode site**.

The Corrosion Cell

A complete corrosion cell consists of four primary elements:

1. **Anode:** The site where current leaves the metal and corrosion occurs.
2. **Cathode:** The site where current reenters the metal.
3. **Electrolyte:** The medium (such as soil or water) that conducts the current.
4. **Metallic Connection:** The physical path (like a pipeline) allowing the flow of electrons.



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Figure 1-1: Corrosion of a pipeline due to localized anode and cathode sites.

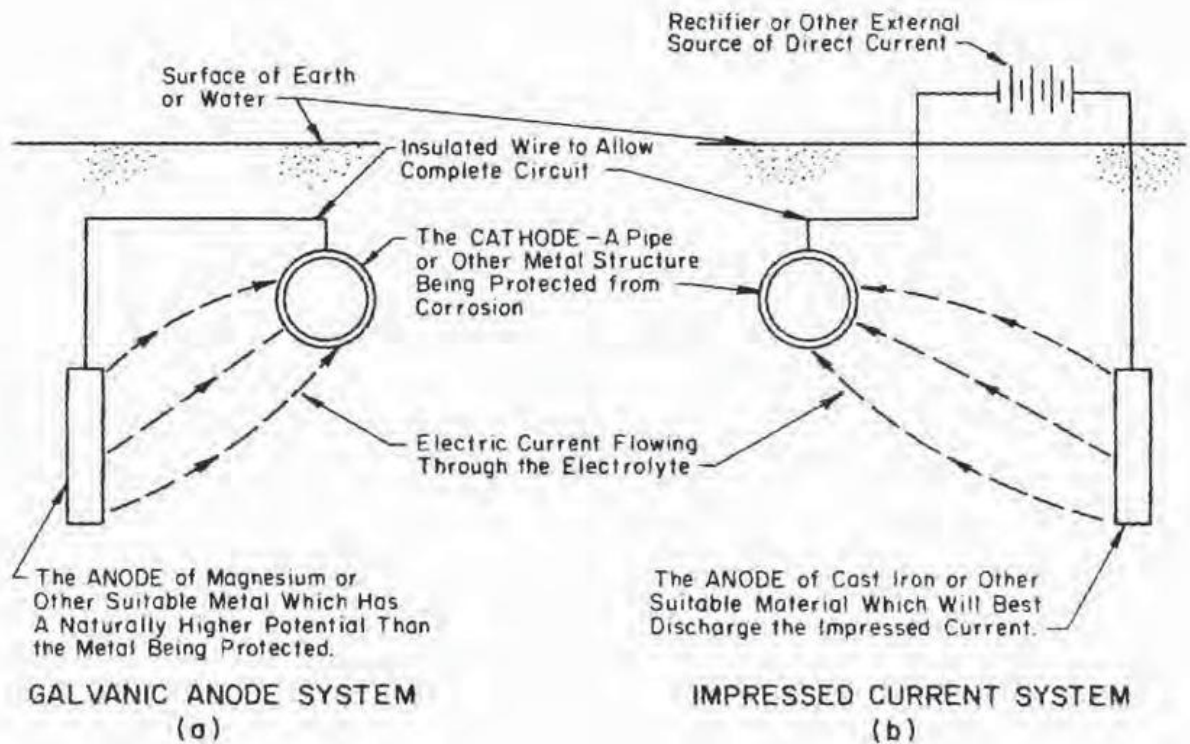
Current flow is driven by a potential difference; the anode potential is **more negative** than the cathode potential, serving as the driving force for the corrosion current.

Principles of Cathodic Protection

Engineering control is achieved by **minimizing the potential difference** between the anode and cathode. By applying current from an outside source, the entire structure is brought to a **uniform potential**, eliminating the existence of active anode and cathode sites.

Types of Cathodic Protection Systems

Effective design requires selecting between two main system types: **Galvanic** and **Impressed Current**.



U.S. Air Force

Figure 1-2: (a) Galvanic and (b) impressed current systems for cathodic protection.

System Comparison

Feature	Galvanic (Sacrificial) System	Impressed Current System
Driving Force	Natural potential difference between metals.	External power source (Rectifier).
Anode Materials	Magnesium or Zinc.	High-silicon cast iron or Graphite.
Operation	Anode corrodes sacrificially to protect the structure.	Rectifier converts A.C. to D.C. for adjustable output.
Connectivity	Requires insulated metallic connection (wire).	Requires insulated metallic connection (wire).

⚠ Safety Constraint: For any cathodic protection system to function, you **must** ensure three essential items are present: anodes, a continuous electrolyte from the anode to the structure, and an external metallic wire connection.

💡 Design Tip: Galvanic systems are often preferred for their simplicity, making use of the higher potential of metals like **magnesium** or **zinc** compared to steel.

📊 Calculation Note: The rectifier in an impressed current system is **adjustable**, allowing engineers to maintain the proper D.C. power level throughout the operational life of the system.

Checkpoint Quiz

1. Which component of a corrosion cell is the site where the actual deterioration of the metal occurs?

- a) Electrolyte
- b) Cathode
- c) Anode
- d) Metallic connection

Answer: (c). The anode is the site where current leaves the structure, causing electrochemical deterioration.

2. What is the primary difference in the power source between galvanic and impressed current systems?

- a) Galvanic systems use D.C. batteries; Impressed current uses A.C. power.
- b) Galvanic relies on natural potential differences; Impressed current uses an external rectifier.
- c) Galvanic systems require no wiring; Impressed current requires insulated leads.
- d) There is no difference in how they are powered.

Answer: (b). Galvanic systems utilize the inherent corrosive potentials of different metals, whereas impressed current systems use a rectifier to drive current from an external source.

3. In an impressed current system, what materials are most commonly selected for anodes?

- a) Pure copper
- b) Zinc or Magnesium
- c) High-silicon cast iron or Graphite.
- d) Aluminum alloys

Answer: (c). High-silicon cast iron and graphite are the standard materials used for anodes in impressed current cathodic protection.

Module 2: Cathodic Protection Design

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the essential preliminary data required for cathodic protection design.
- **Select** between galvanic and impressed current systems based on soil resistivity and current density requirements.
- **Calculate** the number of anodes needed for both sacrificial and impressed current systems using standard engineering formulas.

Executive Summary: Successful cathodic protection design relies on accurate preliminary data, including structure dimensions, soil resistivity, and current density requirements. Engineers must evaluate site-specific variables to determine whether a galvanic or impressed current system is the most technically and economically viable solution.

Design Fundamentals: Required Information

Before a system can be designed or a system type selected, certain preliminary data must be gathered.

- **Physical dimensions and Drawings:** Use structure dimensions (length, width, height, diameter) to calculate the total surface area requiring protection. Drawings must include sizes, shapes, material types, and locations of structure parts.
- **Electrical isolation:** Parts of a structure may be isolated by insulators (e.g., at building inlets or valves). Every isolated part requires its own cathodic protection.
- **Short circuits:** Eliminate contacts between different pipe systems that cause interference.
- **Corrosion history:** Study area records and consult facilities personnel to identify abnormal conditions and reinforce corrosivity predictions.
- **Electrolyte resistivity survey:** Corrosion rate is proportional to electrolyte resistivity. Low resistivity allows more current flow, causing rapid corrosion.

Table 2-1. Corrosivity of soils on steel based on soil resistivity

Soil resistivity range (ohm-cm)	Corrosivity
0 to 2000	Severe
2000 to 10,000	Moderate to severe
10,000 to 30,000	Mild
Above 30,000	Not likely



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