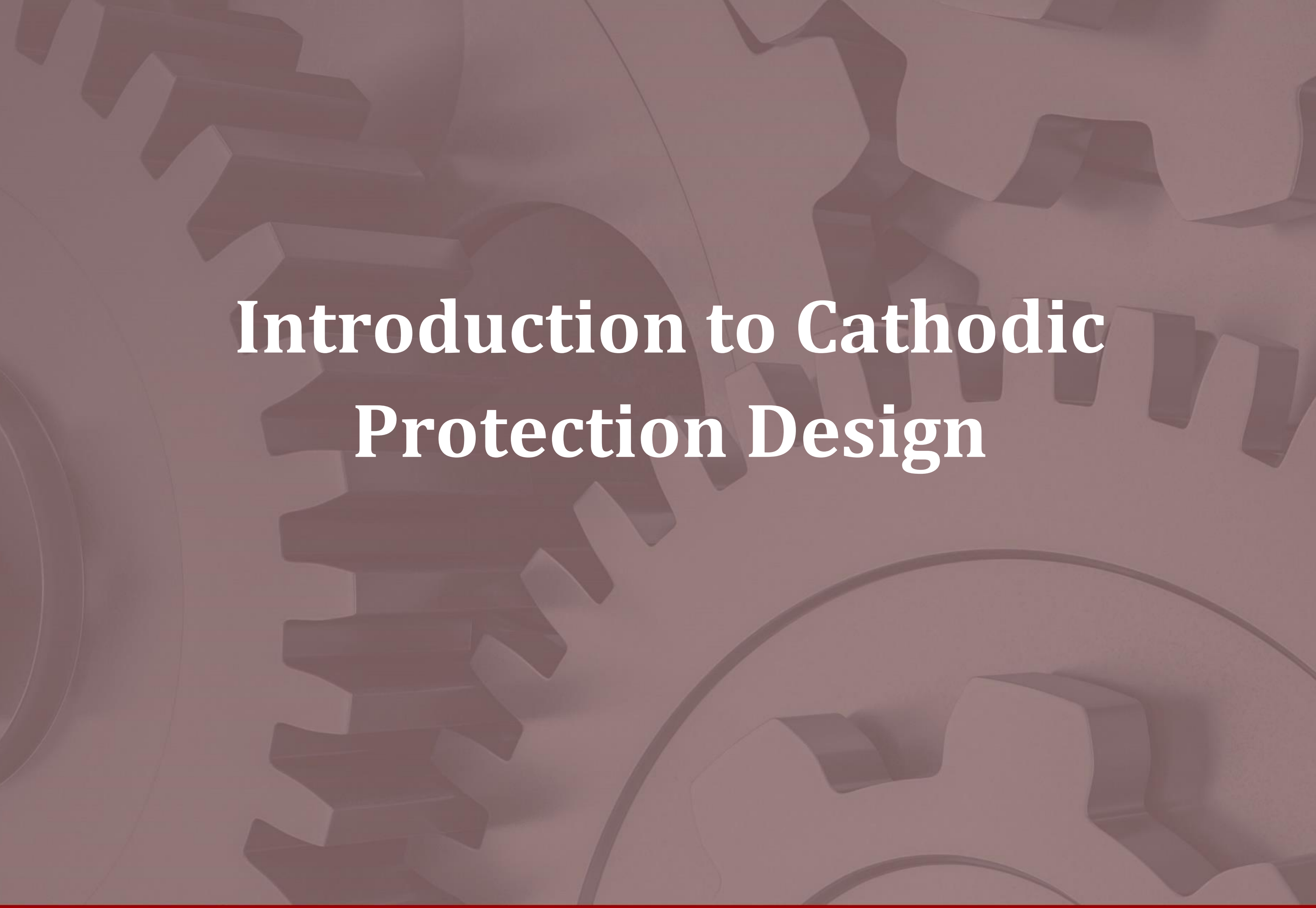

Introduction to Cathodic Protection Design

An Online Continuing Education Course for Engineers

Course Number: MA-4002

Credit: 4 Hours / 4 PDH / 4 CPD

CHAPTER 1
INTRODUCTION TO CATHODIC PROTECTION

1-3. Corrosion.

Corrosion is an electrochemical process in which a current leaves a structure at the anode site, passes through an electrolyte, and reenters the structure at the cathode site as figure 1-1 shows. For example, one small section of a pipeline may be anodic because it is in a soil with low resistivity compared to the rest of the line. Current would leave the pipeline at that anode site, pass through the soil, and reenter the pipeline at a cathode site. Current flows because of a potential difference between the anode and cathode. That is, the anode potential is more negative than the cathode potential, and this difference is the driving force for the corrosion current. The total system—anode, cathode, electrolyte, and metallic connection between anode and thode (the pipeline in fig 1-1)—is termed a corrosion cell.

1-4. Cathodic protection.

Cathodic protection is a method to reduce corrosion by minimizing the difference in potential between anode and cathode. This is achieved by applying a current to the structure to be protected (such as a pipeline) from some outside source. When enough current is applied, the whole structure will be at one potential; thus, anode and cathode sites will not exist. Cathodic protection is commonly used on many types of structures, such as pipelines, underground storage tanks, locks, and ship hulls.

1-5. Types of cathodic protection systems.

There are two main types of cathodic protection systems: galvanic and impressed current. Figure 1-2 shows these two types. Note that both types have anodes (from which current flows into the

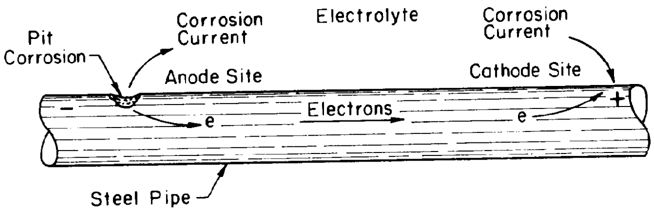

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Figure 1-1. Corrosion of a pipeline due to localized anode and cathode sites.

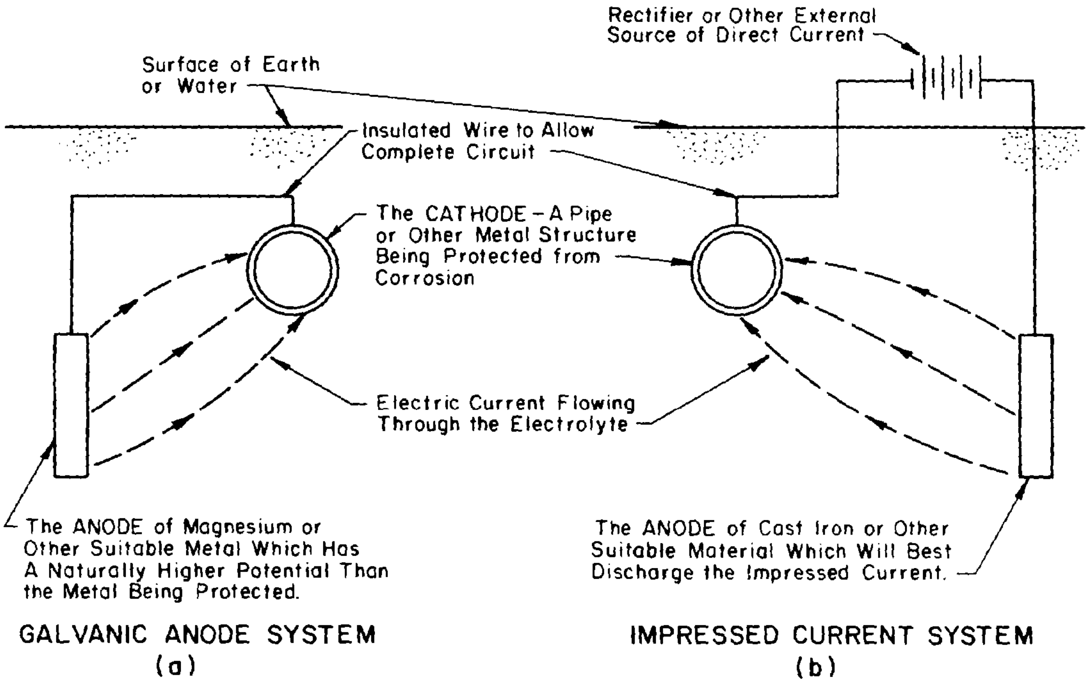

Figure 1-2. (a) Galvanic and (b) impressed current systems for cathodic protection.

electrolyte), a continuous electrolyte from the anode to the protected structure, and an external metallic connection (wire). These items are essential for all cathodic protection systems.

a. Galvanic system. A galvanic cathodic protection system makes use of the corrosive potentials for different metals. Without cathodic protection, one area of the structure exists at a more negative potential than another, and corrosion results. If, however, a much less inert object (that is, with much more negative potential, such as a magnesium anode) is placed adjacent to the structure to be protected, such as a pipeline, and a metallic connection (insulated wire) is installed between the object and the structure, the object will become the anode and the entire structure will become the cathode. That is, the new object corrodes sacrificially to protect the structure as shown in figure 1-2. Thus, the galvanic cathodic protection system is called a *sacrificial anode cathodic protection system* because the anode corrodes sacrificially to protect the structure. Galvanic anodes are usually made of either magnesium or zinc because of these metals' higher potential compared to steel structures.

b. Impressed current systems. Impressed current cathodic protection systems use the same elements as the galvanic protection system, only the structure is protected by applying a current to it from an anode. The anode and the structure are connected by an insulated wire, as for the galvanic system. Current flows from the anode through the electrolyte onto the structure, just as in the galvanic system. The main difference between galvanic and impressed current systems is that the galvanic system relies on the difference in potential between the anode and structure, whereas the impressed current system uses an external power source to drive the current, as figure 1-2b shows. The external power source is usually a rectifier that changes input a.c. power to the proper d.c. power level. The rectifier can be adjusted, so that proper output can be maintained during the system's life. Impressed current cathodic protection system anodes typically are high-silicon cast iron or graphite.

CHAPTER 2
CATHODIC PROTECTION DESIGN

2-1. Required information.

Before deciding which type, galvanic or impressed current, cathodic protection system will be used and before the system is designed, certain preliminary data must be gathered.

a. Physical dimensions of structure to be protected. One important element in designing a cathodic protection system is the structure's physical dimensions (for example, length, width, height, and diameter). These data are used to calculate the surface area to be protected.

b. Drawing of structure to be protected. The installation drawings must include sizes, shapes, material type, and locations of parts of the structure to be protected.

c. Electrical isolation. If a structure is to be protected by the cathodic system, it must be electrically connected to the anode, as figure 1-2 shows. Sometimes parts of a structure or system are electrically isolated from each other by insulators. For example, in a gas pipeline distribution system, the inlet pipe to each building might contain an electric insulator to isolate inhouse piping from the pipeline. Also, an electrical insulator might be used at a valve along the pipeline to electrically isolate one section of the system from another. Since each electrically isolated part of a structure would need its own cathodic protection, the locations of these insulators must be determined.

d. Short circuits. All short circuits must be eliminated from existing and new cathodic protection systems. A short circuit can occur when one pipe system contacts another, causing interference with the cathodic protection system. When updating existing systems, eliminating short circuits would be a necessary first step.

e. Corrosion history of structures in the area. Studying the corrosion history in the area can prove very helpful when designing a cathodic protection system. The study should reinforce predictions for corrosivity of a given structure and its environment; in addition, it may reveal abnormal conditions not otherwise suspected. Facilities personnel can be a good source of information for corrosion history.

f. Electrolyte resistivity survey. A structure's corrosion rate is proportional to the electrolyte resistivity. Without cathodic protection, as electrolyte resistivity decreases, more current is allowed to flow from the structure into the electrolyte; thus, the structure corrodes more rapidly. As electrolyte resistivity increases, the corrosion rate decreases (table 2-1). Resistivity can be measured either in a laboratory or at the site with the proper instruments. Appendix A explains the methods and equipment needed to complete a soil resistivity survey. The resistivity data will be used to calculate the sizes of anodes and rectifier required in designing the cathodic protection system.

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

g. Electrolyte pH survey. Corrosion is also proportional to electrolyte pH (see glossary for definition of pH and other terms). In general, steel's corrosion rate increases as pH decreases when soil resistivity remains constant.

h. Structure versus electrolyte potential survey. For existing structures, the potential between the structure and the electrolyte will give a direct indication of the corrosivity. According to NACE Standard No. RP-01, the potential requirement for cathodic protection is a negative (cathodic) potential of at least 0.85 volt as measured between the structure and a saturated copper-copper sulfate reference electrode in contact with the electrolyte. A potential which is less negative than -0.85 volt would probably be corrosive, with corrosivity increasing as the negative value decreases (becomes more positive).

i. Current requirement. A critical part of design calculations for cathodic protection systems on existing structures is the amount of current required per square foot (called *current density)* to change the structure’s potential to -0.85 volt. The current density required to shift the potential indicates the structure's surface condition. A well coated structure (for example, a pipeline well coated with coal-tar epoxy) will require a very low current density (about 0.05 milliampere per square foot); an uncoated structure would require high current density (about 10 milliamperes per square foot). The average current density required for cathodic protection is 2 milliamperes per square foot of *bare* area. The amount of current required for complete cathodic protection can be determined three ways:

—An actual test on existing structures using a temporary cathodic protection setup.

—A theoretical calculation based on coating efficiency.

—An estimate of current requirements using tables based on field experience.

(1) The second and third methods above can be used on both existing and new structures. Appendix B contains a detailed review of current requirement testing.

(2) Current requirements can be calculated based on coating efficiency and current density (current per square foot) desired. The efficiency of the coating as supplied will have a direct effect on the total current requirement, as equation 2-1 shows:

$$I = (A)(I')(1.0-CE), \qquad \text{(eq 2-1)}$$

where I is total protective current, A is total structure surface area in square feet, I' is required current density, and CE is coating efficiency. Equation 2-1 may be used when a current requirement test is not possible, as on new structures, or as a check of the current requirement test on existing structures. Coating efficiency is directly affected by the type of coating used and by quality control during coating application. The importance of coating efficiency is evident in the fact that a bare structure may require 100,000 times as much current as would the same structure if it were well coated.

(3) Current requirements also can be estimated from table 2-2. The table gives an estimate of current, in milliamperes per square foot, required for complete cathodic protection. That value, multiplied by the surface area of the structure to be protected (in square feet) gives the total estimated current required. Caution should be used when estimating, however, as under- or overprotection may result.

Table 2-2. Typical current density requirements for cathodic protection of uncoated steel

Environment	Current density (mA/sq ft)	
	AFM 88-9[a]	Gerrard[b]
Neutral soil	0.4 to 1.5	0.4 to 1.5
Well aerated neutral soil	2 to 3	2 to 3
Wetsoil	1 to 6	2.5 to 6
Highly acidic soil	3 to 15	5 to 15
Soil supporting active sulfate-reducing bacteria	6 to 42	Up to 42
Heated soil	3 to 25	5 to 25
Stationary freshwater	1 to 6	5
Moving freshwater containing dissolved oxygen	5 to 15	5 to 15
Seawater	3 to 10	5 to 25

[a] Data are from Air Force Manual AFM 88-9, *Corrosion Control* (U.S. Air Force, August 1962), chap 4, p 203.

[b] Data are from J.S. Gerrard, "Practical Applications of Cathodic Protection," *Corrosion*, Vol 2 (L.L. Shreir, Ed.), Newnes-Butterworths, London, 1976, p 11:65. Used with permission.

j. Coating resistance. A coating's resistance decreases greatly with age and directly affects structure-to-electrolyte resistance for design calculations. The coating manufacturers supply coating resistance values.

k. Protective current required. By knowing the physical dimensions of the structure to be protected, the surface area can be calculated. The product of the surface area multiplied by current density obtained previously in *I* above gives the total current required.

l. The need for cathodic protection. For existing structures, the current requirement survey *(I* above) will verify the need for a cathodic protection system. For new systems, standard practice is to assume a current density of at least 2 milliamperes per square foot of bare area will be needed to protect the structure. (However, local corrosion history may demand a different current density.) In addition, cathodic protection is *mandatory* for underground gas distribution lines, and for water storage tanks with a 250,000-gallon capacity or greater. Cathodic protection also is required for underground piping systems located within 10 feet of steel reinforced concrete because galvanic corrosion will occur between the steel rebar and the pipeline.

2-2 Determining type and design of cathodic protection system.

When all preliminary data have been gathered and the protective current has been estimated, the design sequence can begin. The first question to ask is: which type (galvanic or impressed current) cathodic protection system is needed? Conditions at the site sometimes dictate the choice. However, when this is not clear, the criterion used most widely is based on current density required and soil resistivity. If the soil resistivity is low (less than 5000 ohm-centimeters) and the current density requirement is low (less than 1 milliampere per square foot), a galvanic system can be used. However, if the soil resistivity and/or current density requirement exceed the above values, an impressed current system should be used. Figure 2-1 will be used in the design sequence. Design sequences for each type of cathodic protection system are given in paragraphs a and *b* below.

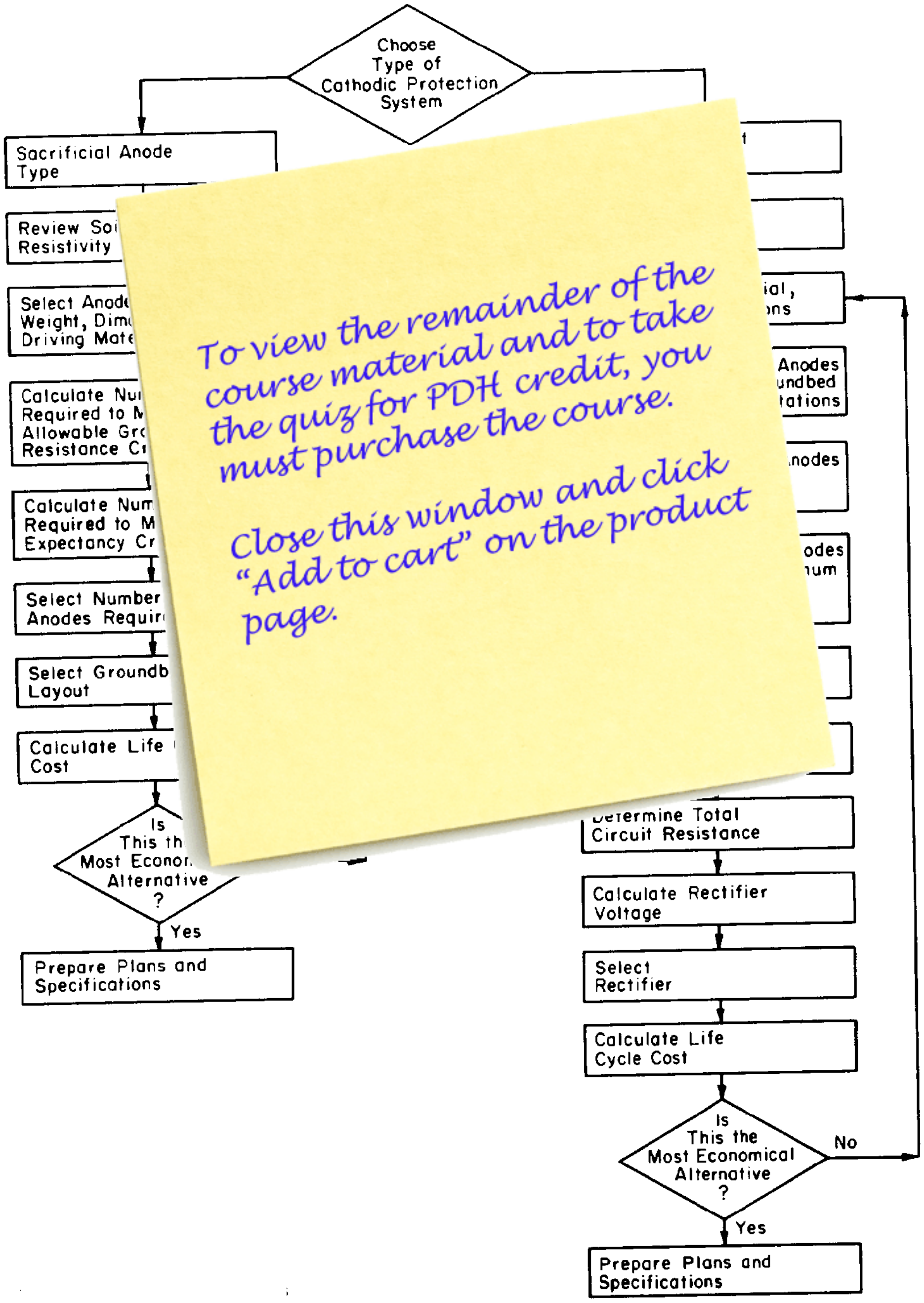

Figure 2-1. Design sequence for cathodic protection systems.