CHAPTER 31

CATHODIC PROTECTION

31-1. General cathodic protection systems

Cathodic protection is a system utilized to inhibit corrosion of structures, such as underground pipes, tanks, etc. 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. For example, 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. 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 cathode is termed a corrosion cell.
For corrosion to occur, the following conditions are required.

a. Electrodes. An anode and cathode must be present.

b. Electrical potential. An electrical potential between the anode and cathode must be present. Several conditions may cause this potential.

c. Conductive path. A metallic conductive path electrically connecting the anode and cathode must exist. In the case of a metallic pipeline, the pipe itself is this conductive path.

d. Electrolyte. The anode and cathode are immersed in an electrically conductive electrolyte that is ionized. Usual soil moisture or water fulfills this condition.

e. Current. When these conditions exist, an electric current will flow, and where the current leaves a metallic object, metals will be consumed. Cathodic protection reverses the current flow by installing ground beds of sacrificial anodes. No longer does the current leave the structure. Now the structure receives current flow, inhibiting corrosion. The structure is the cathode, and thus, the term cathodic protection.

31-2. Types of cathodic protection systems

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. There are two main types of cathodic protection systems: galvanic and impressed current.

a. Galvanic systems. 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 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. 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 an impressed current system 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. The external power source is usually a rectifier that changes input alternating current (AC) power to the proper direct current (DC) 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.

31-3. Application of cathodic protection

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

c. Insulators. If a structure is to be protected by the cathodic system, it must be electrically connected to the anode. 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 in-house 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. 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. 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. Resistivity can be measured either in a laboratory or at the site with the proper instruments. The resistivity data will be used to calculate the sizes of anodes and rectifier required in designing the cathodic protection system.

g. Electreolyte pH. 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. For existing structures, the potential between the structure and the electrolyte will give a direct indication of the corrosivity. According to National Association of Corrosion Engineers (NACE) Standard RP-0169, Control of External Corrosion on Underground or Submerged Metallic Piping Systems (1996), 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 that is less negative than -0.85 volt would probably be corrosive, with corrosivity increasing as the negative value decreases (becomes more positive).

h. Current density. 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). Current requirements can be calculated or estimated 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. 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. Caution should be used when estimating, however, as underprotection or overprotection may result. 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.

i. Verification of need. For existing structures, the current requirement survey 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 (Department of Transportation regulations - Title 49, *Code of Federal Regulations*) 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.

31-4. Cathodic protection system design

The process required to design a cathodic protection system is described below.

a. Galvanic systems. Eight steps are required for applying a galvanic protection system.

(1) The site of lowest resistivity will likely be used for anode location to minimize anode-to-electrolyte resistivity. In addition, if resistivity variations are not significant, the average resistivity will be used for design calculations.

(2) Galvanic anodes are usually either magnesium or zinc. Zinc anodes are used in extremely corrosive soil (resistivity below 2000 ohm- centimeters). Data from commercially available anodes must be reviewed. Each anode specification will include anode weight, anode dimensions, and package

dimensions (anode plus backfill). In addition, the anode’s driving potential must be considered.

(3) The net driving potential for the anodes must be determined.

(4) Determine the number of anodes needed to meet groundbed resistance limitations.

(5) Determine the number of anodes for the system's life expectancy

(6) Select number of anodes to be used.

(7) Select ground bed layout.

(8) Determine the life-cycle cost for proposed design.

b. Impressed current systems. Eleven steps are required for applying an impressed current protection system.

(1) Review soil resistivity.

(2) Review current requirement test.

(3) Select anode.

(4) Determine the number of anodes needed to satisfy the current density limitations.

(5) Determine the number of anodes for the system's life expectancy.

(6) Determine the number of anodes needed to meet the maximum anode groundbed resistance requirements.

(7) Select anodes to be used.

(8) Select the area for placement of the anodes.

(9) Determine the total circuit resistance.

(10) Calculate the rectifier voltage.

(11) Select a rectifier.