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CATHODIC PROTECTION SYSTEM DESIGN III --

Sacrificial Anode System Design Principles for Underground Structures

The most common application of cathodic protection is controlling corrosion on buried structures, such as pipelines and storage tanks. The design of a cathodic protection system for such structures is described in detail in MIL-HDBK 1004/10. For underground structures, both impressed current and sacrificial anode cathodic protection systems are feasible and the most appropriate system is chosen based on life cycle cost for the system. Therefore, in order to select the most cost effective system, it is common to make a preliminary design of both types of systems for a specific application so that the life cycle costs can be estimated. The design of both types of system requires a pre-design field survey as described in Techdata Sheet 2020-SHR. In this survey, information required to establish the amount of current required for protecting the structure is developed. This current requirement is the same whether the structure is protected using a sacrificial or impressed current system and is the basis for the remainder of the system design.

In the design of a sacrificial anode cathodic protection system, the principal design factors that need to be determined are the material to be used for the sacrificial anodes and number and size of anodes that will be required to provide current to protect the system for the life of the system. The size and shape of the anodes, along with the characteristics of the soil, determine the amount of current that can be supplied by each anode. The life of the anodes depends on: the material used for the anodes, the weight of the anodes, and the current output.

The two materials that are commonly used for sacrificial anodes in underground applications are magnesium and zinc. There are two types of magnesium anodes: a **high potential alloy** and the **standard alloy**. The zinc alloy most commonly used for underground service is ASTM B148, Type II.

The current output from an anode depends on the potential difference between the anode and the structure being protected and the effective resistance between the anode and the structure being protected (including both the metallic and electrolytic paths). Methods for calculating the effective circuit resistances are given in MIL-HDBK 1004/10. In cases where the anodes are located fairly close (within 10 feet) to the structure to be protected and the soil resistivity is above 500 ohm-cm, a simplified method of calculating anode outputs can be used. The formula used is:

Formula 1

$$i = \frac{C\,f\,y}{r}$$

where:

i = current output, milliamperes
C = anode material factor
f = anode size/shape factor
y = structure potential factor
r = soil resistivity

The factors are given in MIL-HDBK 1004/10. An example of a typical calculation is:

C = 120,000 for a high potential magnesium anode

f = 1.06 for a packaged 32-pound anode

y = 1.00 for a structure potential of -850 mV versus Copper/Copper Sulfate

r = 2,000 ohm-cm

$$i = \frac{120,000 \times 1.06 \times 1.00}{2,000} = 63.6 \text{ milliamps}$$

If the information from the pre-design field survey indicated that the structure to be protected required 1.5 amperes of protective current, then the number of 32-pound high potential magnesium anodes required for protection of the structure would be:

Formula 2

$$\text{No. of Anodes} = \frac{\text{Total Current Required}}{\text{Current Output per Anode}} = \frac{1500}{63.6} = 23.6$$

In this case we would use 24 anodes to supply the required current.

The next step in the design is to determine the life of the anodes. The basic principle of this calculation is that each anode material will produce a specific amount of current from the corrosion of a given amount of anode material.

Magnesium is consumed at a rate of 17 pounds per ampere year. However, the consumption rate of magnesium depends on the current density on the anode and an efficiency factor is usually included in calculating the consumption of magnesium anodes as described in MIL-HDBK 1004/10. Zinc is consumed at a rate of 26 pounds per ampere year and this rate is not as affected by current density as the rate of magnesium consumption.

The life of an anode at a given output is determined by the formula:

Formula 3

$$Y = \frac{W}{S\,I}$$

where:

Y = anode life, years
W = weight of anode, pounds
S = anode consumption rate, pounds per ampere year
I = current output, amperes

For the 32-pound magnesium anodes, each producing 63.6 mA of current, and assuming a typical anode consumption rate of 17 pounds per ampere year, the anode life would be:

$$Y = \frac{32 \text{ pounds}}{17 \text{ pounds per ampere year} \times 0.0636 \text{ amperes}} = 29.5 \text{ yr}$$

In an actual final design, it might be necessary to evaluate anodes of different composition and size to balance the number of anodes and the anode life. Anodes with higher potential will give a higher current output. Anodes with a shape approaching a sphere will have a high ratio of weight to surface area and will have a low current output and a long life. On the other hand, anodes that are long, wide, and thin will have a low ratio of weight to surface area and have a high current output and short life.

In practice, the rough design calculations given above are usually sufficient for the initial comparison that is used to determine whether a sacrificial anode system or impressed current system will be used.

A more detailed description of the design of sacrificial anode cathodic protection systems is given in MIL-HDBK 1004/10 and will also be covered in the next three Techdata Sheets in this series.