

Cathodic Protection Of Water Storage Tanks

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Introduction

Protecting water storage tanks from corrosion through the application of cathodic protection devices is an accepted practice for most newly constructed water storage tanks in the United States. The increased use of cathodic protection for these structures is credited to the growing awareness that this is an economical means of controlling corrosion on submerged surfaces.¹

The Corrosion Mechanism

The corrosion of submerged metallic structures is caused by electrochemical activity. In freshwater tanks, corrosion activity usually results in a concentrated pitting attack that causes quicker wall penetration than if the corrosion was more uniformly distributed on the metal surface. This attack is initiated by the development of anodic and cathodic areas on the submerged metal surfaces. Anodic areas will suffer corrosion, whereas cathodic areas will not.

Metal in contact with an electrolyte, such as a tank containing water, is analogous to a group of interconnected galvanic cells like the battery shown in Figure 1. The current leaves the metal at the negative (or anode), flows through the water and returns to the tank at the positive (or cathode). The tank itself provides the return portion of the circuit from positive to negative.

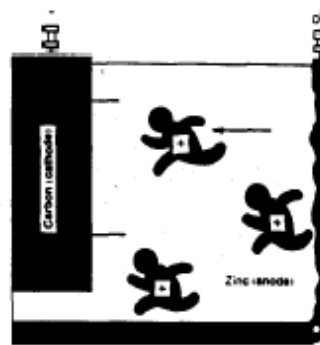


Figure 1

In a typical dry cell battery, current is generated by two electrodes immersed in an electrolyte where a difference in potential exists between electrodes. The difference in potential between the zinc casing and the carbon electrode form a galvanic cell that causes current

to flow from the casing (zinc anode) through the electrolyte to the carbon rod (cathode) and returns back through the light bulb to the zinc case. In this process, the zinc is destroyed by corrosion.

Metallic ions leaving the surface of the structure at the anodic portions form oxides (or sulfates, chlorides, or hydroxides, depending on the chemical composition of the electrolyte), and a film is gradually built up around the anodic portions. Such corrosion products act to limit the rate of flow of current with a consequent shift in the location of the anodic area. The corrosion pattern may be that of many anodic and cathodic areas creating general corrosion, or it may consist of fewer anodic areas, resulting in concentrated corrosion activity.

There are a number of mechanisms that initiate corrosion of steel submerged in water tanks.

Uniform Corrosion

Although steel visually appears to be homogeneous, close inspection shows that it is quite irregular, consisting of many grains of metal that are electrically different from each other. Thus, some will be anodes and others will be cathodes. The corrosion attack will usually appear as random, closely spaced pits (Figs 2 and 3).

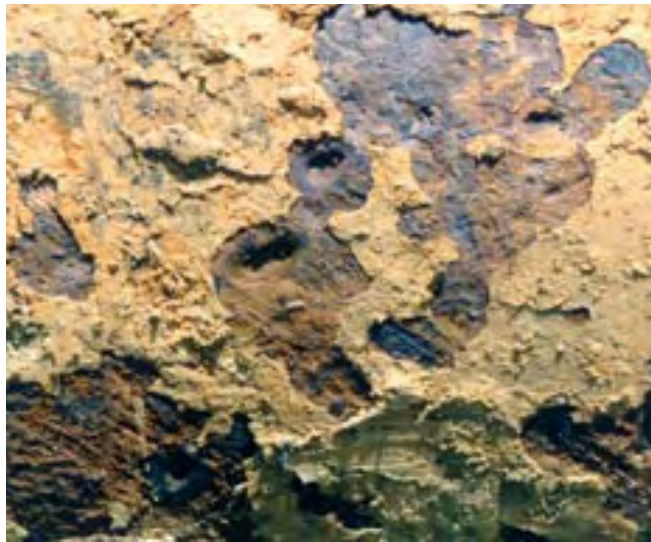


Figure 2 and 3

Stressed Metal

Usually, steel that is under stress will be anodic to unstressed steel. In tanks, these stresses can be caused by welding or through bending or forming (without stress relieving), bolting, and riveting. Usually, the fastener will be anodic to the adjacent plate.

Dissimilar Metal Corrosion

The use of different metals in direct contact with each other will establish a corrosion cell in which the more noble metal will be cathodic and the more active metal will be anodic.

Examples of such cells in tanks are copper or stainless steel heater coils in industrial fire protection tanks and weld seams where the metallurgy of the welding rod differs from the base plate metal.

Crevice Corrosion

A corrosion cell develops at crevices where oxygen concentrations entrap ion cells. Generally, the anodic area will be in the crevice with the nearby surface areas rendered cathodic. In water tanks, these develop most commonly between the head and plate of bolted or riveted plates and between the overlapping areas of unsealed plates.

Differential In Oxygen Concentrations

When steel is immersed in water and some of the steel surface is exposed to a relatively oxygen-enriched water compared with other steel surfaces, the area deprived of oxygen will be rendered anodic in relation to surfaces exposed to abundantly oxygenated water. This phenomenon is often observed in bare or poorly coated tanks in which the lower submerged surfaces are heavily corroded (there are lower oxygen levels at greater depths), whereas the upper areas show little corrosion. Even more common is vertical striation corrosion. Deep, vertical gouges, sometimes several inches or even feet long, occur on the uncoated submerged surfaces of the tanks (Fig 4). This common corrosion phenomenon is



Figure 4

caused by the development of an initial corrosion pit that generates soft, oozing corrosion products. Gravity causes these products to slough down the side of the tank wall, shielding the lower surface from oxygen and rendering it anodic. The shielded surface begins to corrode, generating more corrosion products. The process continues over and over down the wall of the tank.

Coating Pinhole Corrosion

When the internal surfaces of tanks are coated with a dielectric material, i.e. vinyl or epoxy, the corrosion activity will be concentrated at the holidays (holes) in the coating. The breaks in the coating can result from mechanical damage, improper surface preparation, or merely microscopic voids in the coating surface.

The corrosion currents will therefore concentrate at the holidays and result in higher corrosion current densities at these locations. Even though a good coating reduces the total metal loss, a complete penetration of the metal surface usually occurs more quickly than if the tank were not coated (Fig. 5).

The Need For Corrosion Control

Many other factors can influence the rate at which corrosion processes will proceed in water tanks. Among the most significant are electrolyte resistivity, water flow

rates, the extent of anodic surface areas relative to cathodic areas, iron ion concentrations, temperature, and water level fluctuations.

Thus, virtually all potable waters are corrosive with respect to steel. Almost all tank owners require that tanks be coated. If water were not corrosive, coating maintenance expenditures of \$2 to \$3/ft² of submerged area would not be spent every five to ten years to prevent corrosion. Therefore, the question is not whether water tanks are subject to destructive corrosion; the question is what is the most effective and economical means of corrosion mitigation.



Figure 5

A four-year study by the U.S. Navy concludes:³

“Cathodic protection has been shown to be an economical and effective method for protecting the immersed interiors of steel water tanks. Cathodic protection of a water tank can double or triple the time between recoatings. Thus, cathodic protection and protective coatings should be considered as components of a single corrosion control program for water storage tanks. Automatically controlled cathodic protection systems utilizing one reference half-cell should be installed in steel water storage tanks throughout the naval shore establishment. “

Another recent report concluded:⁴

“Supplemental cathodic protection should be used to prevent the corrosion that can occur at ‘holidays’ in organic coatings.”

A brochure prepared by the Steel Plate Fabricators Association summarizes:⁵

“The modern techniques of corrosion control using coatings and cathodic protection can reduce the initial cost and will extend the life of the steel storage tank indefinitely.”

Finally, a study by the author indicates that the cost of installing cathodic protection is usually less than half the cost of repainting the submerged surface area of most tanks. Since cathodic protection can double or triple the time between recoating, the economics of using cathodic protection for corrosion control on water tanks are apparent. In fact, many municipalities have abandoned recoating tanks in favor of total corrosion control using cathodic protection. Ronald Klimko of the City of Cleveland, Ohio, Department of Public Utilities states:⁶

“Our costs to recoat the interior of an average tank runs between \$30,000 and \$40,000 plus the cost of welding pita and structural repairs. The cost of a cathodic protection system for the same tank is less than one third of the recoating costs. For the City of Cleveland, the economics are obvious.”

Design Of Cathodic Protection

A number of variables associated with each water tank must be considered when a cathodic protection system is designed. Among these are the water chemistry, the coating, and tank design, and the function of the tank.

Variations in water chemistry that affect cathodic protection include the water source, total dissolved solids, total hardness, dissolved oxygen, total alkalinity, pH, temperature, and bacteria.

Variations in tank coatings include the generic type and

condition of the coating. There are also a number of tank designs and shapes, including ground storage reservoirs, standpipes, and elevated water storage tanks. In addition, tanks are used as water storage facilities, pressure regulators, wash reservoirs, fire protection reservoirs, or any combination of these.

Because of these varying conditions, it would appear to be unreasonable to expect a limited number of cathodic protection designs to accommodate all. Yet, this is possible, because a number of conditions in water tanks and treatment equipment favor standardization.

First, the electrolyte, i.e., the water in which the metal is submerged, is relatively uniform. Second, although there are a number of structural shapes, they are all basically a combination of cylinders and gradual curves. These conditions contrast with those found in underground pipelines where there is considerable irregularity in electrolyte uniformity and piping configuration. Third, and most responsible for permitting standardized design, cathodic protection systems for water tanks are almost always of the rectifier type. Great flexibility can be built into a rectifier system to meet a variety of requirements without adding greatly to the cost.⁷ Magnesium and other types of galvanic anode materials are almost never used because they are usually more costly than rectifier systems and are not as flexible.

When designing a cathodic protection system for a water storage tank, the designer must determine the total amount of current required for protection, the resistivity of the water, the anode materials, the anode geometry, and the service life.

Electric Current Required

The total electric current required for cathodic protection is determined by multiplying the total submerged surface area by a preselected current density. Although current density requirements can vary in fresh waters from as little as 0.1 milliamperes to 5.0 milliamperes/ft² of bare submerged surface area, a maximum design current density of 2.5 milliamperes/ft² will suffice for more than 98 percent of all structures. If less current is re-

quired, the rectifier output can be reduced in the field. Some factors that increase the actual operating current are temperature, turbulence, chlorides, and sulfides. Factors such as high alkalinity reduce the current requirement.

The most important factor, however, is the type and condition of the coating. Although there are a number of coatings available for the interiors of water storage tanks, there appears to be an ever increasing trend toward the use of epoxy coatings.

When a high quality coating is applied and used with cathodic protection in accordance with AWWA standards and manufacturers' specifications, a useful life of 30 or more years can be expected. When it is realized that an uncoated water tank of 10 million gallon capacity can require as much as 150 amperes of current, whereas a similar well coated tank might need as little as 5 to 10 amperes, the value of quality coating used in conjunction with cathodic protection is apparent. Typical maximum currents for various sizes of uncoated water storage tanks are listed in Table 1.

TABLE 1

Maximum currents of various sizes of uncoated water tanks

Capacity ML	Current	
	gal	A
0.37	100,000	5 - 10
1.89	500,000	20 - 30
3.78	1,000,000	30 - 60
18.92	5,000,000	60-100

A coating serves a different function on a cathodically protected structure. If coating is the only means of controlling corrosion, then blistering, peeling, or cracking of 1-2 percent of the coated surface causes failure of the paint system to control corrosion. In most cases, accelerated attack will occur.

In a cathodically protected tank, comparable coating deterioration is compensated for by a small increase in the cathodic protection system's electrical current output. The coating's major function with cathodic protec-

tion is to reduce the cost of power and the rate of anode consumption. Repainting the submerged portions of the structure can, therefore, be done less frequently.

Electrolyte Resistivity

The design of a cathodic protection system requires measurement of the water resistivity. This resistivity is a major factor governing the electrical circuit resistance that, in turn, governs the voltage at which the system operates to deliver the required current. Higher voltage means greater power consumption, and the greater the power consumption, the higher the operating costs.

A longer anode results in lower circuit resistance and lower operating costs, but a greater anode length means a higher initial cost. Therefore, the designer must strike the optimum economic balance between initial cost and operating cost. Since most treatment waters in the United States vary in resistivity from 2000-10,000 ohm-cm, it is usually possible to vary the number and size of the anodes to reduce the circuit resistance so that maximum voltage requirements range from 10 to 80 volts.

Previous Anode Materials And Configurations

In the past, if the anode material was not subject to winter icing damage, high silicon cast iron anodes were often used (Fig. 6). These anodes had a minimum design life of 10 years and therefore eliminated the annual expenditure required to replace aluminum anodes.

If a water tank was subject to winter icing conditions, aluminum anodes were used. These expendable aluminum anodes were of extruded 2017-T4 alloy of at least 15 mm (1/2 in) diameter and of sufficient size and length to provide for one full year of operation (Fig. 7). These anodes must be replaced each spring. The article about the City of Cleveland experiences reported:

"In 1956, the City first tested a manually controlled cathodic protection system for effectiveness against corrosive action in the interior of an elevated tank. The system became inoperative five months later and evalu-

ation of its potential was impossible. The primary problem was ice formation in the tank during the winter. The ice destroyed the anode suspension system, rendering the system useless. Anode fragments dropping into altitude valve risers required complete valve disassembly for repair. “

An improved anode installation system suspends the anode wire material in a circular loop configuration to conform to the geometry of the tank (Fig. 8-10). This installation technique has several advantages over earlier systems. Primary among these are the fact that it provides the most even distribution of current for optimum performance tailored to the size and shape of the particular tank. The only exceptions would be overly tall standpipes or tanks of unusual decorative design where long vertical anode systems may be advantageous.

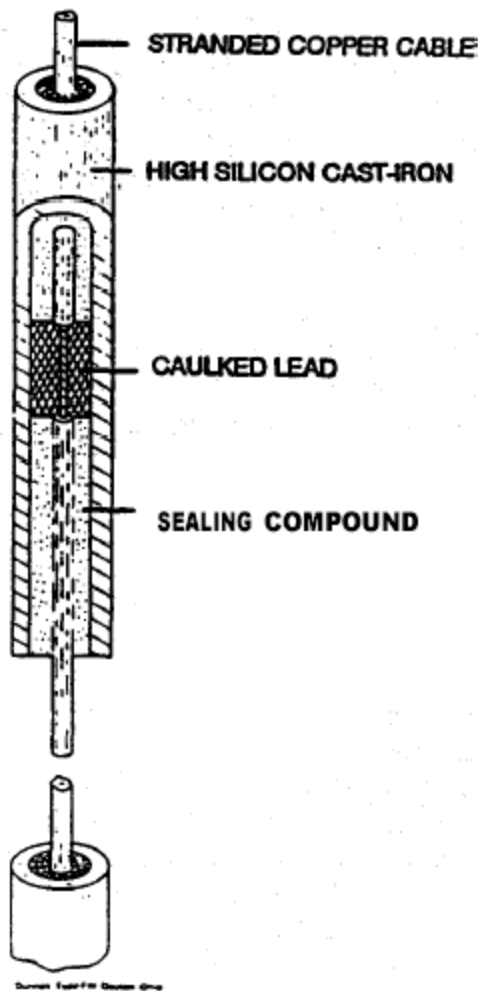


Figure 6

This new anode suspension technique is ideally suited where a long lived anode system is desired in a tank subject to icing conditions. The flexible suspension system is designed so the anode material cannot come in contact with the tank ice during normal fluctuation in water level. Hence the tank receives cathodic protection all year round and there is no need for yearly replacement of ice damaged anodes.

The loop suspension system also eliminates the need for hand holes (plus covers and insulated support brackets) and the maintenance problems involved with these. There is no need to cut numerous holes in the top of the tank. Typically this was done after the tank was coated thereby creating the need for touch up work. These hand holes were also subject to their own corrosion problems as well as being a source for contamination if they were not tight fitting. With the new loop system, the limited number of small metal hangers required for the suspension material can be easily welded to the inside of the tank before the coating is applied.

Modern Anode Systems

An alternative to these roof supported anode systems has been developed over the last 10 years using a small diameter precious metal wire anode system. The anode material used for this application is platinized niobium wire, which is installed through a flexible suspension system that prevents ice from contacting the anodes (Fig. 8-10) in northern climate tanks. Since the anode geometry better conforms to the shape of the tank, more uniform cathodic protection current distribution to the tank's interior surfaces is an added benefit.

Advantages Of The Platinized Niobium System

The consumption rate of platinized niobium is .00008 to .0013 lb compared with 14 lb/amp year for aluminum and .5 to 1.0 lb/amp year for Hi silicon cast iron anodes. This means that the design life for the platinized niobium anode is often in excess of 20 years. Also, a wire anode system operates continuously throughout the year, whereas an aluminum anode system may be inoperative for more than five months of the year.

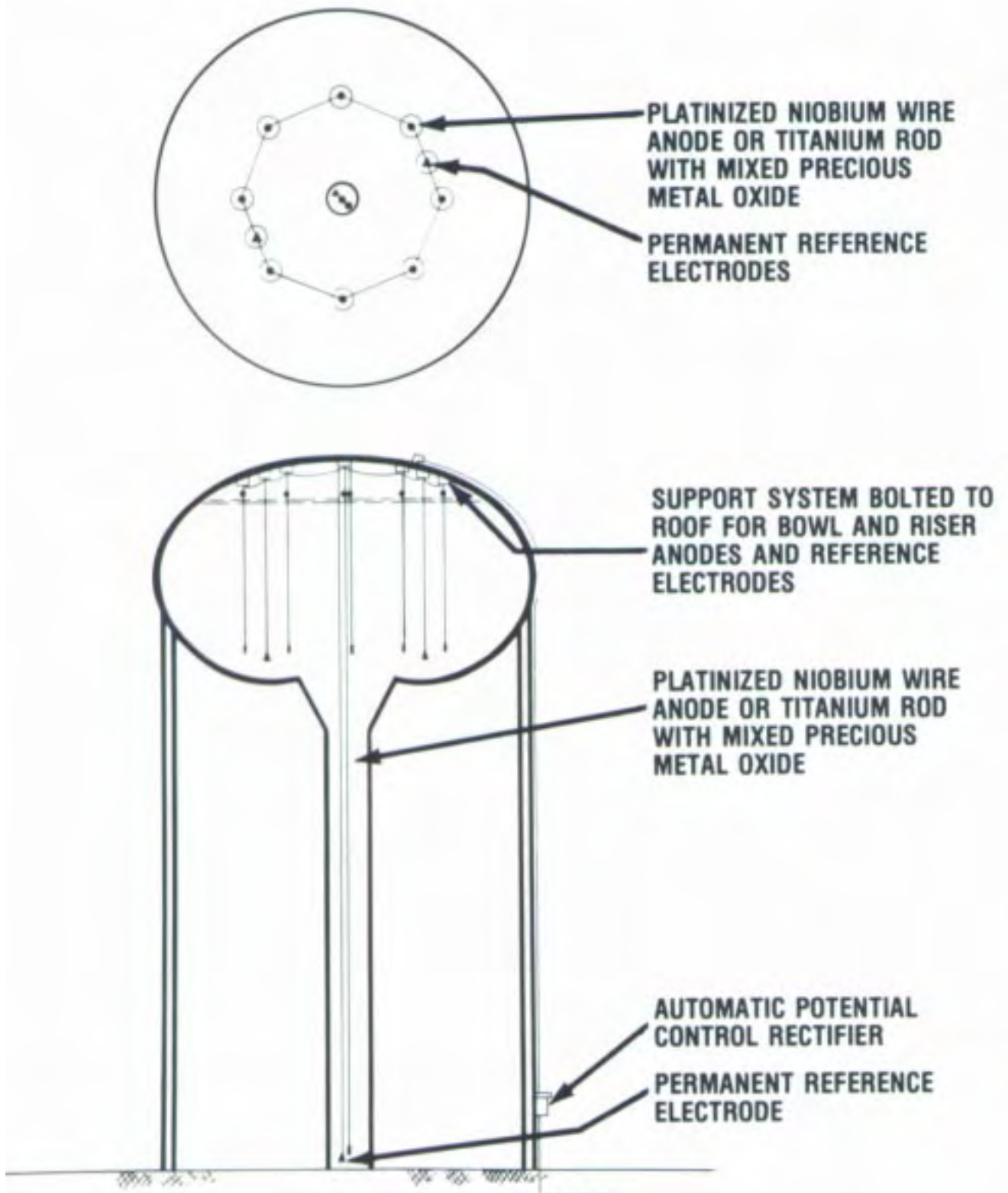


Figure 7

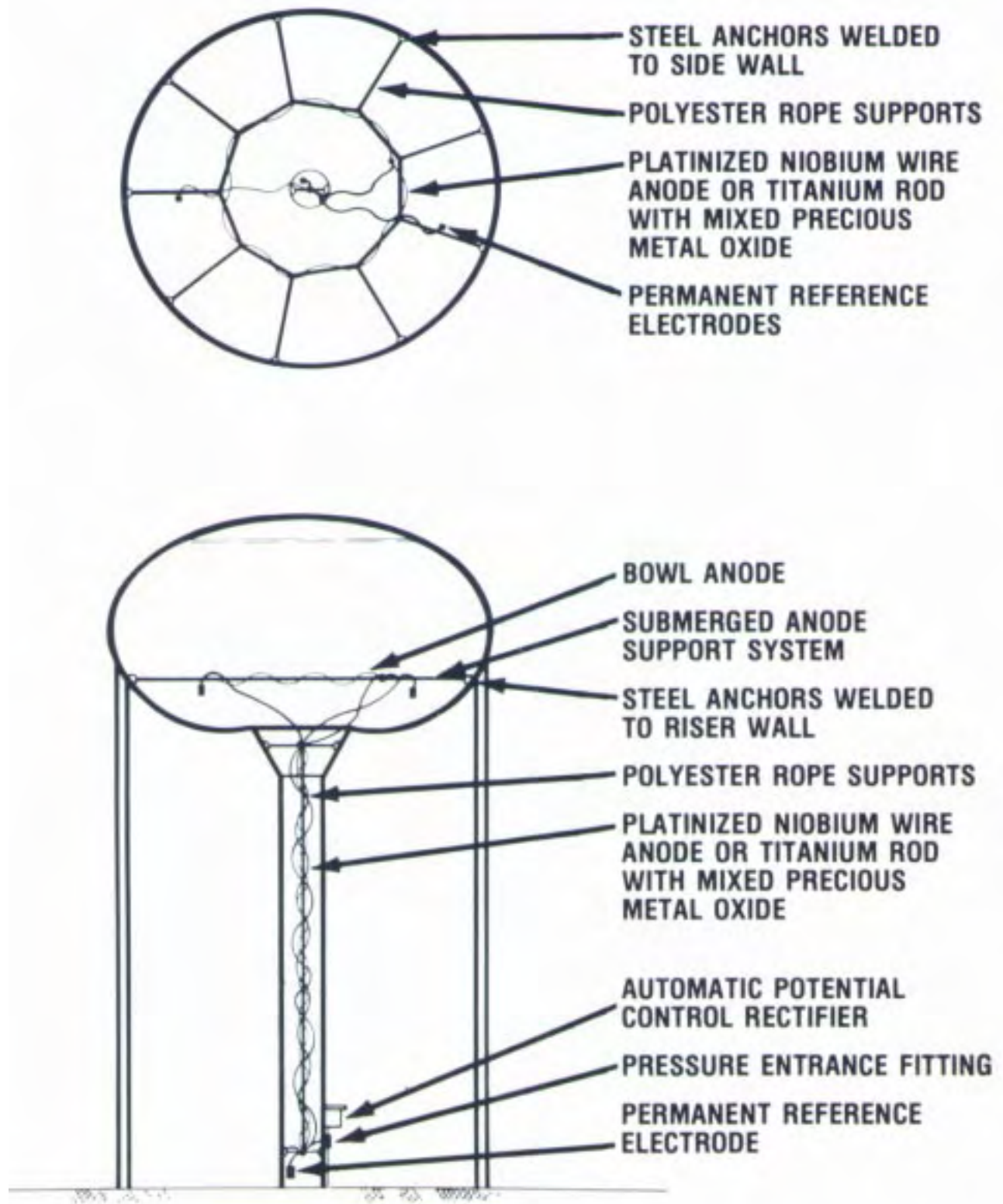


Figure 8

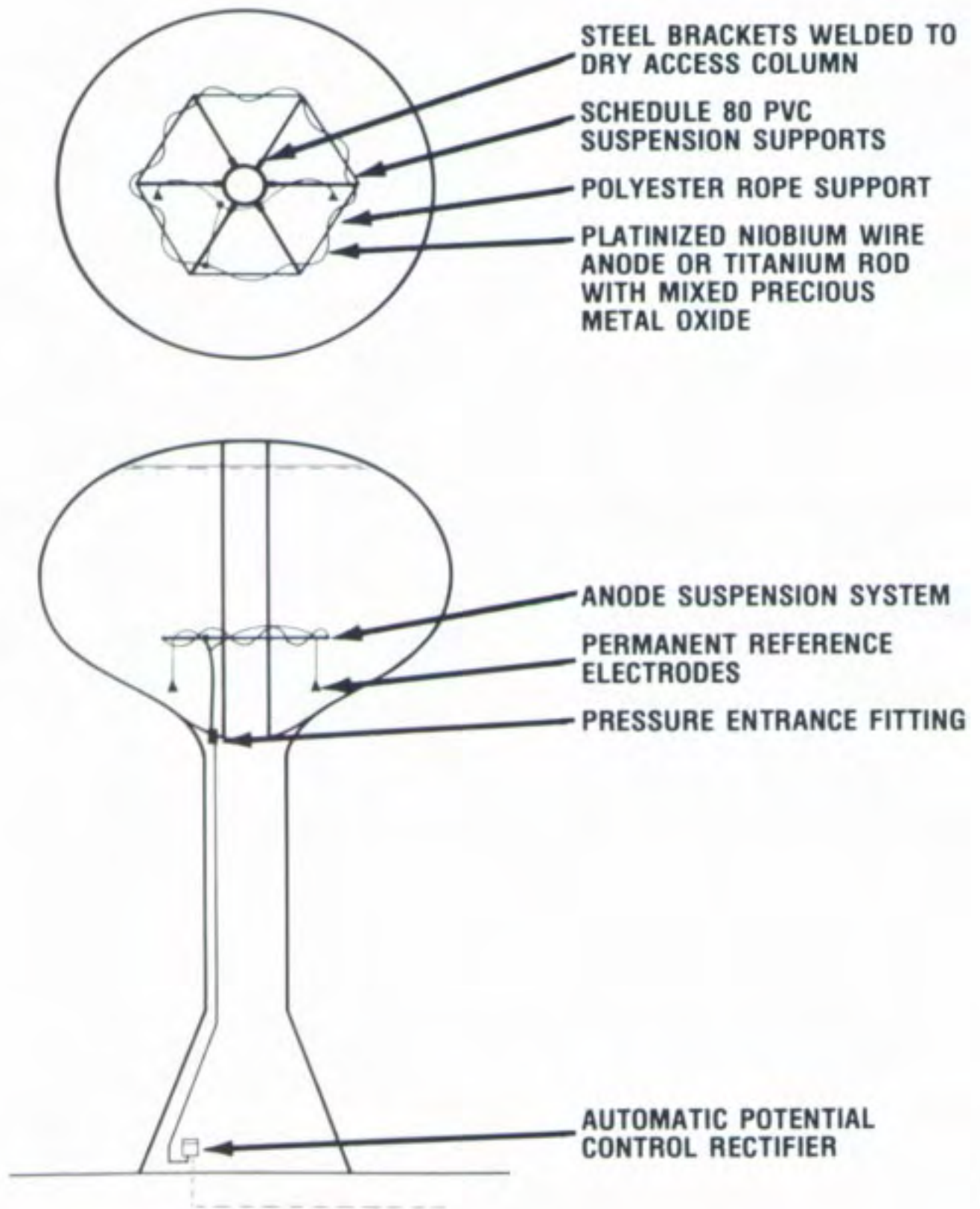


Figure 9

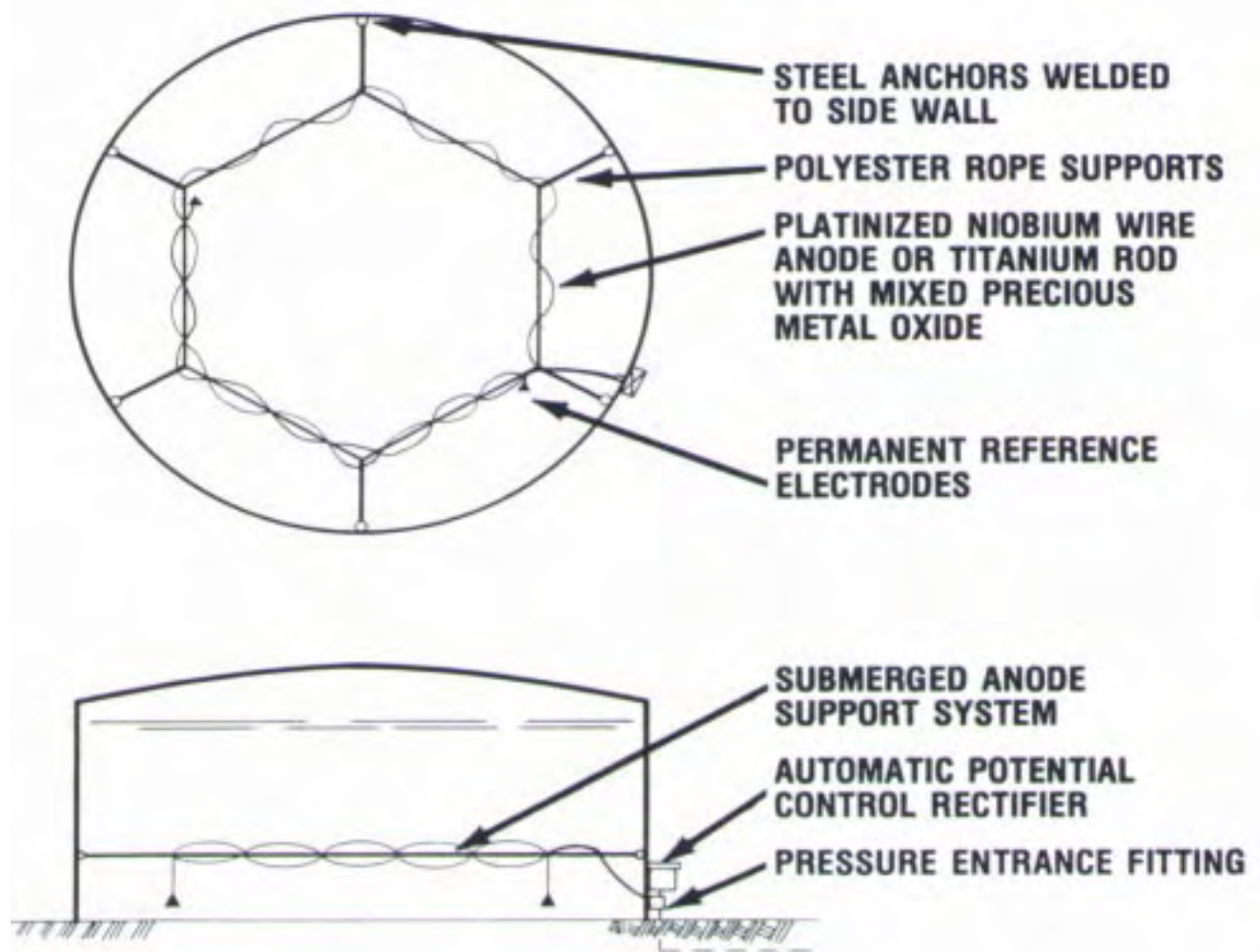


Figure 10

When aluminum anodes are torn down by icing conditions, the damaged anode rods accumulate on the tank's bottom, or worse, in the riser, leading to significant expenditures for periodic cleaning. The cost of aluminum anode materials has increased annual service and maintenance expenditures to the extent that the short term economics of three to five years favor the permanent anode system.

The report on the City of Cleveland continues:⁶

“The new anode system was first installed in one of the wash water tanks where levels fluctuated dramatically

several times a day. Level drops of more than 3 m (10 ft) in less than 2 minutes were not uncommon. The suspension system worked regardless of the variances without a problem. After a year of testing, we began to consider another installation. This would subject the system to critical tests of survival under severe icing conditions. The system proved to be a complete success in several elevated tanks in our area.”

Anode Geometry

In earlier anode systems, after the optimum anode length was calculated, the anodes were suspended in the water in a configuration that would provide, as nearly as

possible, an even distribution of the cathodic protection current.

The anodes were usually suspended vertically within the tank bowl in concentric rings (Figs 8-10). The outer most ring of the anodes was usually full length and was designed to protect the tank walls and some of the tank bottom. The inner ring anodes, called stub anodes, were considerably shorter in length, since they protect only the bottom of the tank. The ratio of the number and length of anodes was designed to assure as even as possible distribution of current to the area each anode protects. In elevated water storage tanks having wet risers more than 350 mm (30 in) in diameter, a full-length riser anode was also normally provided. Since the ratio of the riser anode length to area protected is usually larger than the ratio of the bowl anode length to area protected, the rectifier unit was usually equipped with a second output control using a rheostat to allow the current output of the riser anode to be reduced.

Each anode string was typically suspended from a porcelain insulator bolted through the tank roof (Fig. 11). Immediately adjacent to the insulator, a hand hole was cut through the roof to provide for inspection and replacement of anode material. The rectifier unit was usually mounted at the base of the tank ladder. This location is preferred since the wiring and conduit that carry the rectifier output to the top of the tank are run up the ladder support struts.

When a long lived anode system is incorporated for icing conditions, the anode wire material is suspended in a circular fashion to provide for even distribution of current. The flexible suspension system must be designed so that the anode material cannot come in contact with the tank surfaces or ice during normal fluctuations in water level.

Automatic Controllers

During the past few years, several automatic control systems have been developed to compensate for changes in current requirements for cathodic protection. These changes result from fluctuating water levels, changes in water chemistry, and coating deterioration.

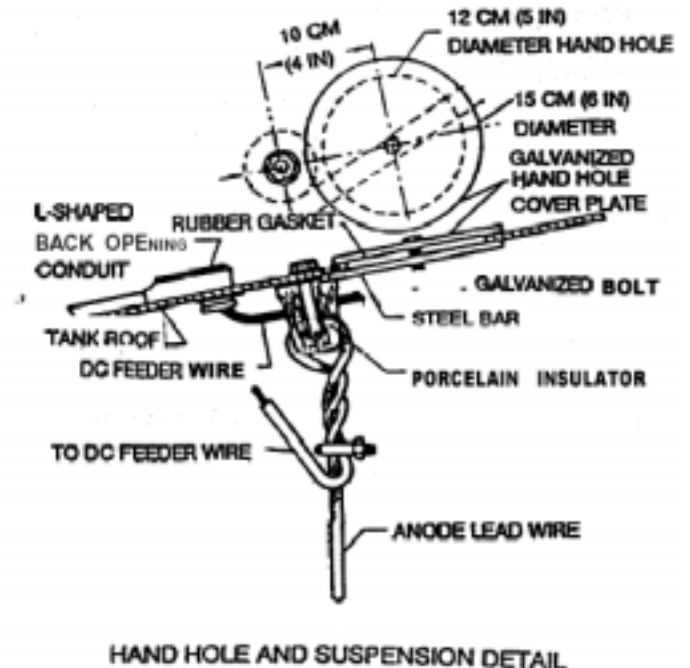


Figure 11

The U.S. Navy report states:³

“An automatically controlled cathodic protection system for steel water tank interiors is a reliable safeguard for ensuring that the immersed surfaces are receiving full protection from corrosion without excessive use of current or damage to the coating.”

The study by Meyers and Obrecht concludes:⁴

“Regardless of the coating efficiency, cathodic protection systems should be automatic potential controlled. This will ensure that any exposed steel immersed in the water is continuously being protected without excessive use of [electric] current or blistering of the coating.”

Automatic voltage control units incorporate a circuit that compares the difference in potential between the reference electrode and the tank against a preset internal voltage. When the structure-to-reference electrode varies from the optimum value, the circuit operates to increase or decrease the anode current so that the optimum voltage will be maintained. These systems automatically compensate for all the variables except for the

voltage drop through an electrolyte, i.e., the IR drop.

Meyers and Obrecht state:⁴

“The success of an automatic potential controlled cathodic protection system, however, depends upon how accurately the tank-to-water potential can be measured. [The] IR drop error between the steel and a permanently installed copper-copper sulfate reference electrode must be eliminated if effective corrosion control is to be obtained. “

One method of reducing IR to zero is to immerse two or three reference electrodes in the tank and to adjust the equipment manually in the field to balance out the IR drop error. Although this technique would appear to be valid, there are problems in application. The reference cells must be balanced manually, and the setting is valid only as long as the water chemistry and coating conditions do not change,

The second approach is to reduce resistance (R) to zero, which would require reducing the resistivity of the water to zero. This is, for all practical purposes, impossible

The third alternative is to reduce the current flowing from the anode to the tank wall to zero. This can be done by interrupting the current output from the rectifier unit. The reading taken immediately after the anode

current is interrupted, called an instant-off reading, is commonly used in corrosion control and is recognized and defined in the NACE Standard RP-01-69.⁸

This technique requires only one reference electrode, with no manual balancing or field compensations necessary. Through the use of solid-state components, the output of anode current for the rectifier is turned off for a fraction of a second, during which time the tank-to-electrolyte potential is measured by the reference electrode and electronically stored in a memory circuit. This memorized reading is then compared with a preset optimum potential and is used to control the output of current during the remaining time period, after which the system recycles. These systems are also equipped with a corrosion potential monitoring voltmeter, which is located in the circuit so that it measures and indicates the instant-off protective level maintained in the tanks (Fig. 12).

The units in this type of system are equipped with an automatic gain control so that the system responds to a given deviation in potential and is automatically adjusted to match specific conditions. The advantages over manual control lie not only in automatically maintaining precise protective levels regardless of changes in water level, water chemistry, and coating deterioration, but also in affording a means of reading the level of protection. Thus, continuous corrosion control can be assured by monitoring the tank's potential voltmeter.

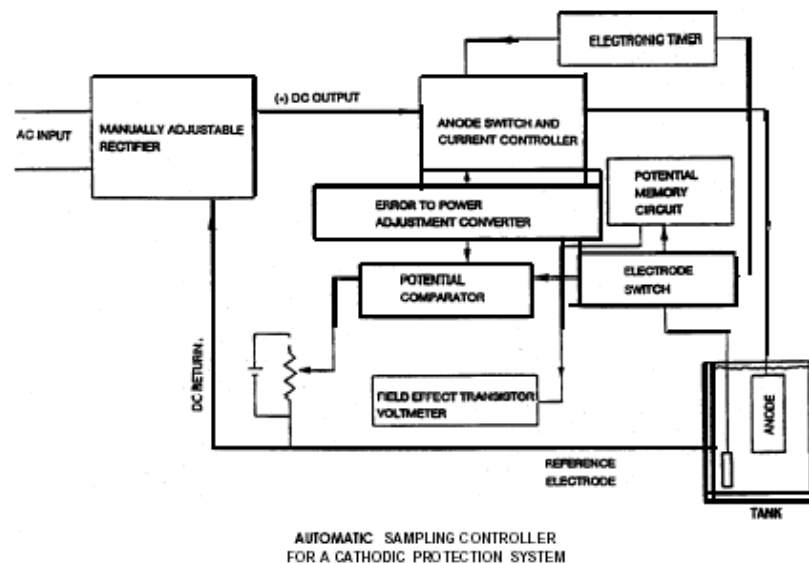


Figure 12

Rectifiers

Rectifier units, used as the power source for cathodic protection, are equipped with a variable tap transformer, selenium or silicon rectifying elements, a DC voltmeter, and a separate ammeter for each output circuit (Fig. 13). The unit normally provides full wave rectification and allows for manual adjustment of the system's maximum voltage in 20 or more steps from 0 to 100 percent of the rated capacity. The unit must be rated so that it can continuously provide the necessary current to protect the internal tank surfaces. The rectifier unit should be housed in a weatherproof cabinet.

The automatic controller is housed with the rectifier unit or in a separate weatherproof cabinet. The U.S. Navy study recommends that the control system "be of completely solidstate design with no electrochemical components and capable of automatically maintaining the tank-to-electrolyte potential at the pre-selected level within an accuracy of 25 millivolts. The tank-to-electrolyte potential measured and maintained by the controller should be free of error produced by IR drop."

The automatic controller usually operates through a copper-copper sulfate (Cu/CuSO_4) reference electrode designed for a minimum five year life. The tank-to-electrolyte difference in potential is then displayed on a calibrated voltmeter. The indicated voltage should also be free from IR drop error and should be simply displayed to permit easy monitoring.

Criteria For Cathodic Protection

A cathodic protection system should be designed so that an adequate level of cathodic protection is maintained in accordance with the criteria for steel given in the Recommended Practice of the NACE RP-01-69. The three most commonly applied criteria are:

1. A negative (cathodic) voltage of at least 0.85 volts as measured between the structure surface and a saturated copper-copper sulfate half-cell contacting the electrolyte. Determination of this voltage is made with the protective current applied. The corrosion engineer should consider voltage (IR) drops other than those across the structure-electrolyte boundary for valid interpretation of the voltage measurement.

2. A negative (cathodic) voltage shift of at least 300 millivolts as measured between the structure surface and a saturated copper-copper sulfate half-cell contacting the electrolyte. Determination of this voltage shift is made with the protective current applied. This criterion applies to structures not in contact with dissimilar metals. The corrosion engineer should consider the voltage (IR) drops other than those across the structure-electrolyte boundary for valid interpretation of the voltage measurements.

3. A minimum negative (cathodic) polarization voltage shift of 100 millivolts measured between the surface of the structure and a saturated copper-copper sulfate

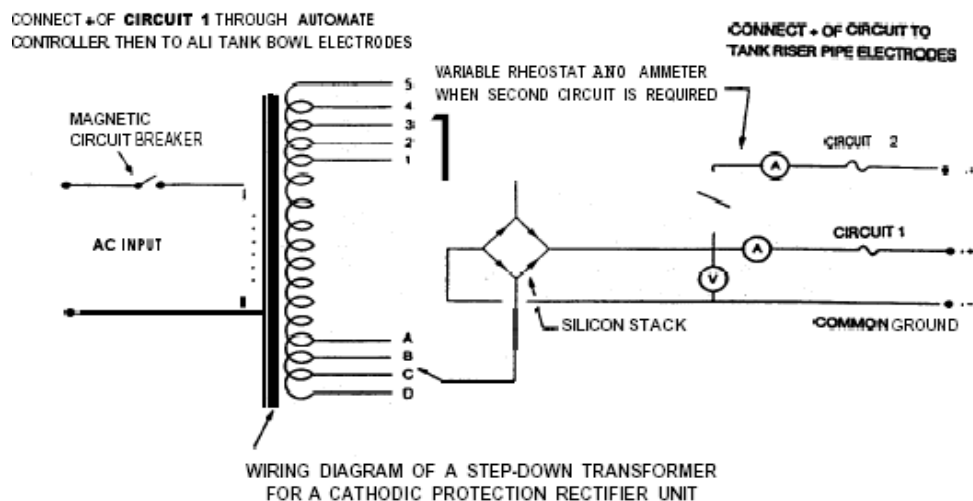


Figure 13

halfcell contacting the electrolyte. This polarization voltage shift is determined by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. The voltage reading after the immediate shift should be used as the base reading from which to measure polarization decay.

An automatic system's accurate performance should be confirmed annually by testing with a portable highimpedance voltmeter and reference electrode. Since consideration must be given to the IR drop through the water resulting from the applied current, the reference electrode should be placed as close as possible to the submerged protected surface, and manual instant-off potentials should be used to authenticate the displayed cathodic protection potential levels. A sufficient number of potential measurements should be observed to confirm that the anode configuration provides the proper distribution of current throughout the tank. Particular attention should be given to crevices and angles along the tank surface. The tank surfaces should not be over protected, since this can contribute to coating deterioration.

Design Life

Most of the components in cathodic protection systems for water storage tanks and water treatment equipment have a design life of 15-20 years. The electric components and the rectifier units are capable of continuous operation over this length of time with little attention. The exception is the anode materials, which consume themselves at various rates. High silicon cast-iron anodes can, through proper design, last 10 or more years in most applications while the newer platinum wire anode systems can be designed for 20 years life.

MAINTENANCE

Regardless of the type of cathodic protection system installed, it should be checked monthly to ensure that it is operating properly. The DC current and voltage outputs of the system, transformer tap adjustments, rheostat settings, and potential set point should all be recorded each month and placed on record for future

reference. If a malfunction is noted, the necessary repairs should be made immediately.

A complete inspection of the cathodic protection system should be performed annually. For manual systems, annual maintenance should include re-adjustment of the system to ensure proper operating levels for the coming year; for systems with aluminum anodes, this service should include the replacement of the anode material. For all manual and automatic systems, the annual inspection should include a potential profile of the submerged structure along with visual and electrical tests.

CONCLUSION

Cathodic protection for the submerged surfaces of water storage tanks is an effective and economical method of corrosion control. Although bare steel tanks can be protected, both coating and cathodic protection are usually recommended for new installations.

Automatically controlled, solid-state rectifiers, which measure the maintained potential without IR drop error, are recommended. Where icing conditions are encountered, a flexible, long-lived anode system using platinumized niobium wire is recommended, although replaceable aluminum anodes can also be used. High silicon cast iron anodes can be used for tanks when icing conditions do not exist. All systems must be properly maintained, however, to ensure continued effective operation and optimum corrosion control.

REFERENCES

1. Bushman, J.B., Cathodic Protection for Municipal and Industrial Water Tanks and Water Treatment Equipment. Seminar Proc., Western Region, NACE, Sec 16, San Dimos, CA (May 1-6, 1970).
2. Parks, L.E., Coating Selections and Maintenance Painting Cost - Pulp and Paper Industry. Material Performance, 16:7:37. NACE, Houston, TX (July, 1977).
3. Drisko, R.W., Surveillance and Automatically Controlled Systems for Cathodic Protection of Water Tank Interiors. Dept of the Navy, Naval Civil Engineering Lab, Technical Report R7605 (Apr. 1972).

4. Meyers, J.R. and Obrecht, M.F., Corrosion Control for Potable Water Storage Tanks. Paper presented at Sixth International Congress on Metallic Corrosion, Sydney, Australia (Dec. 3-9, 1975).

5. New Ideas for Painting Steel Storage Tanks, Steel Plate Fabricator's Association, Inc., Chicago, IL (June, 1977).

6. Klimko, R., Cathodic Protection Guards Cleveland's Water System. Amer. City and County Magazine (March, 1977).

7. Husock, B., Cathodic Protection of Water Storage Tanks, Proc. Sixth Annual Appalachian Underground Corrosion Short Course, West Virginia University, Morgantown, WV (1961).

8. Recommended Practice - Control of External Corrosion on Underground or Submerged Metallic Piping systems. NACE Standard RP-01-69, NACE, Houston, TX (1972).