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An Introduction to Cathodic Protection Concepts, Criteria, Precautions

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1. CONCEPTS

1.1 CORROSION AS AN ELECTROCHEMICAL PROCESS. Corrosion of metals is a result of electrochemical reactions. An electrochemical reaction is a chemical reaction accompanied by a flow of electrical current.

1.1.1 DRIVING FORCE. The driving force for the corrosion of metals through electrochemical reactions is the free energy of the metal atoms in their metallic form. All chemical systems tend to change so that the free energy present is at a minimum. This is analogous to the flow of water downhill to minimize the free energy due to gravity. Most engineering metals are found in nature in a form with low free energy. These metal ores are chemical compounds consisting of the metal atoms combined with other atoms such as oxygen or sulfur. The process of breaking up these ores into their metallic and non-metallic atoms involves an addition of energy in order to free the metal atoms from the natural, low energy content chemical compounds. The corrosion process is driven by the tendency of these metal atoms to revert to their natural state. If corrosion products are analyzed, their chemical composition is usually identical to the ore from which the metal was originally obtained.

1.1.2 THE ELECTROCHEMICAL CELL. Electrochemical reactions occur through a combination of chemical reactions and the exchange of electrical charges (current) between areas where these chemical reactions are occurring. The entire process is commonly known as an electrochemical cell. This process is described in the following paragraphs.

1.1.2.1 COMPONENTS OF THE ELECTROCHEMICAL CELL. Every electrochemical cell consists of an anode, a cathode, an electrolyte and a metallic path for the flow of electrical current between the anode and cathode. A schematic electrochemical cell is shown in Figure 1.

1.1.2.2 REACTIONS IN AN ELECTROCHEMICAL CELL. Chemical oxidation occurs at the anode in an active electrochemical cell. Chemical oxidation is a reaction where an atom or molecule gives up electrons. The chemical shorthand for a typical oxidation reaction is:

Mo -> M+ + e-

where

Mo = metal atom

M+ = metal ion

e- = electron

In this reaction the metal atom, which in combination with the other atoms in a piece of metal has high strength and other metallic properties, is transformed into a metal ion which usually dissolves. The electron is available for transfer to another site of lower electrical potential. At the cathode in an active electrochemical cell, chemical reduction occurs. Chemical reduction is a reaction where an atom or molecule gains electrons. The chemical shorthand for a typical reduction reaction is:

R+ + e -> Ro-
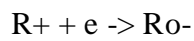
Where

R+ = positive ion in solution

e = electron-

Ro = reduced atom

A reduced atom may either be discharged as a gas or may be deposited on the cathode. The electrolyte in an electrochemical cell serves as a source of material for the chemical reactions, a medium for the deposition of the products of the chemical reactions, and a path for the flow of charged ions in solution. The electron path, usually a metallic connection, is required so that the electrons produced at the anode can flow from the anode to the sites at the cathode where they are consumed. The electrochemical cell consists of an anode where electrons are produced by a chemical reaction, a cathode where electrons are consumed by a chemical reaction different than the one occurring at the anode, an electrolyte for the flow of ions, and a metallic path for

the flow of electrons (dc current). Figure 2 shows an example of a corrosion cell where zinc is connected to platinum in hydrochloric acid. The zinc corrodes at the anode, hydrogen gas forms at the cathode, and electric current flows through the external electron path. This electric current can be made to do useful work. An ordinary dry cell battery is an electrochemical cell. When in storage, the electron path is not completed and the electrochemical reaction which produces the current is only allowed to proceed when the external metallic path is completed.

1.2 THE ELECTROCHEMICAL BASIS FOR CATHODIC PROTECTION. Cathodic protection utilizes a flow of direct current electricity to interfere with the activity of the electrochemical cell responsible for corrosion. As shown in Figure 3, corrosion can be prevented by coupling a metal with a more active metal when both are immersed in an electrolyte and connected with an external path. In this case the entire surface of the metal being protected becomes a cathode; thus the term "cathodic protection."

1.2.1 POTENTIALS REQUIRED FOR CATHODIC PROTECTION. Every metal immersed in an electrolyte develops an electrochemical potential due to the free energy of the atoms in the metal. In order to prevent anodic reactions from occurring due to electrochemical reactions on that metal, electrons must be prevented from leaving the metal. Since electrons can only flow from an area of high (negative) potential to an area with lower (negative) potential, connection of the metal to be protected to a source of more negative electrons can effectively prevent the anodic reaction on the metal to be protected and can thus prevent corrosion. In this case, the flow of electrons is from the external source to the metal being protected. Conventional current flow is described by the flow of imaginary positive charges in a direction opposite the electron flow. Since cathodic protection depends on the energy of electrons and their tendency to flow only from an area of high (negative) potential to one of lower (negative) potential, the principle of cathodic protection can also be demonstrated through a hydraulic analogy (see Figure 4). In this analogy the surge tank is the metal to be protected. Flow from the surge tank is prevented by coupling the tank to a supply of water at higher pressure, leaving the tank full.

1.3 PRACTICAL APPLICATION OF CATHODIC PROTECTION. Cathodic protection is only one of many methods of corrosion control. Cathodic protection should be evaluated as one alternative method to control corrosion in an overall corrosion control program. Application of cathodic protection should be evaluated on the basis of technical feasibility, economic analysis, and system functional requirements such as reliability and consequence of failure. In some cases (e.g., underground pipelines), field experience has shown that cathodic protection is such an effective means of providing the required levels of safety in the operation of the systems that cathodic protection is required by Federal regulation.

1.3.1 WHEN CATHODIC PROTECTION SHOULD BE CONSIDERED. Cathodic protection should be considered, possibly in conjunction with other forms of corrosion control such as the application of protective coatings, wherever the system is exposed to an aggressive environment in such a manner that cathodic protection is technically and economically feasible.

1.3.1.1 WHERE FEASIBLE. Cathodic protection is primarily feasible when the surfaces to be protected are buried or submerged. External surfaces of buried metallic structures, surfaces of metal waterfront structures such as sheet pilings or bearing piles, and the internal surfaces of tanks containing electrolytes such as water are applications where cathodic protection is usually technically feasible and is commonly utilized in protecting such structures. Cathodic protection has limited applicability on internal surfaces of small diameter pipelines and other areas where ion flow in the electrolyte is restricted by electrolyte resistance.

1.3.1.2 WHEN INDICATED BY EXPERIENCE. When construction of a new buried or submerged system is being planned, the corrosivity of the environment should be considered as one of the factors in the design of the system. If experience with similar systems in the vicinity of the construction site has shown that the site conditions are aggressive based upon leak and failure records, cathodic protection should be provided as a means of controlling corrosion on the new system. Cathodic protection is one of the few methods of corrosion control that can be effectively used to control corrosion of existing buried or submerged metal surfaces. Thus, if leak records on an existing system show that corrosion is occurring, cathodic protection may be applied to stop the corrosion damage from increasing. Cathodic protection can, however, only

stop further corrosion from occurring and cannot restore the material already lost due to corrosion.

1.3.1.3 AS REQUIRED BY REGULATION. Regulations by the Department of Transportation (DOT) have established standards for the transportation of certain liquids and compressed gas by pipelines in order to establish minimum levels of safety. These regulations require that these pipelines be protected by cathodic protection combined with other means of corrosion control such as
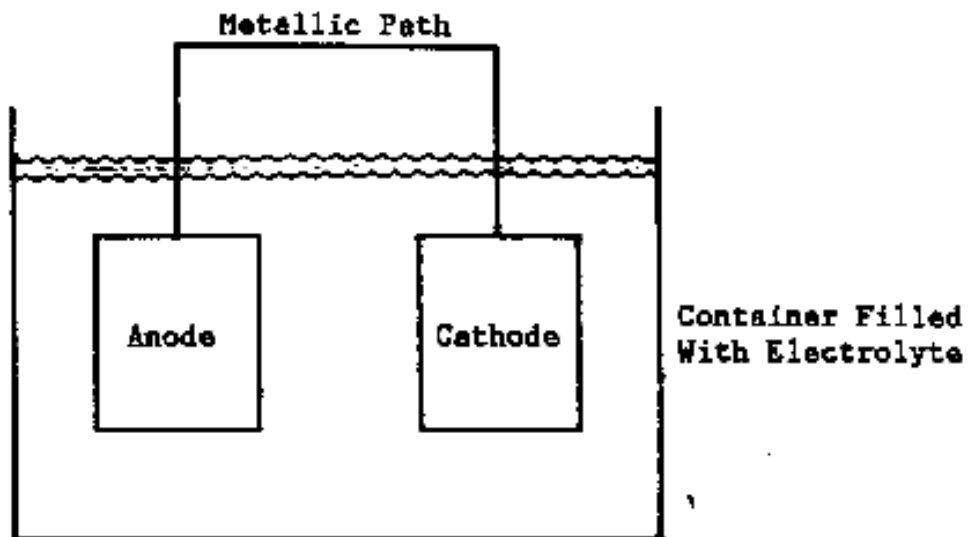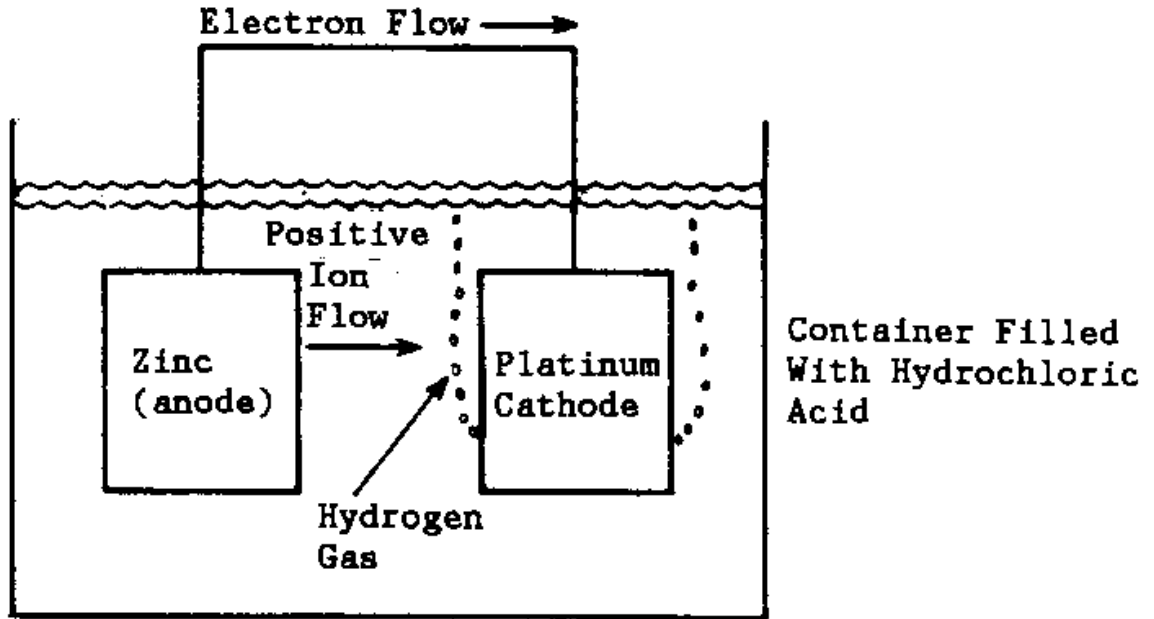
Figure 1

The electrochemical cell

Figure 2

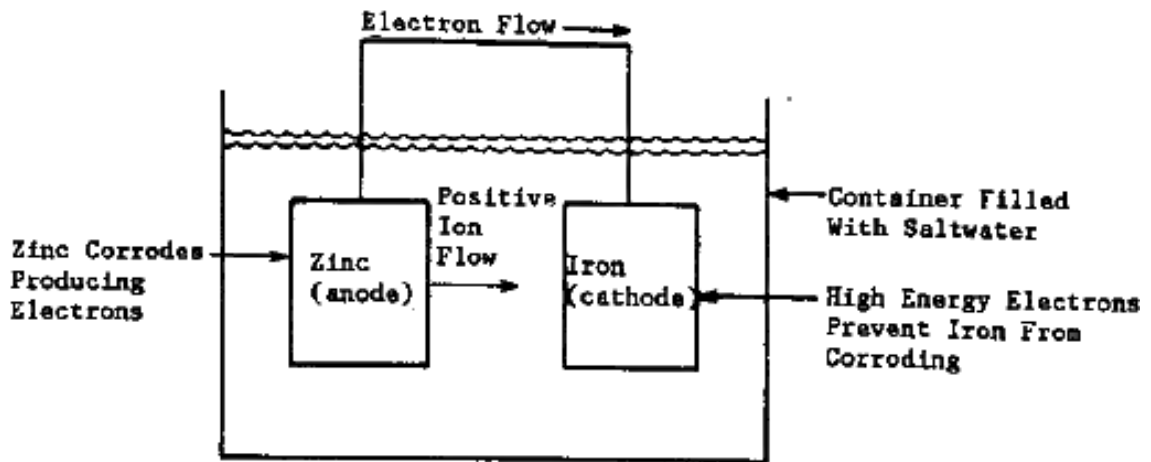Corrosion cell

Zinc and platinum in hydrochloric acid
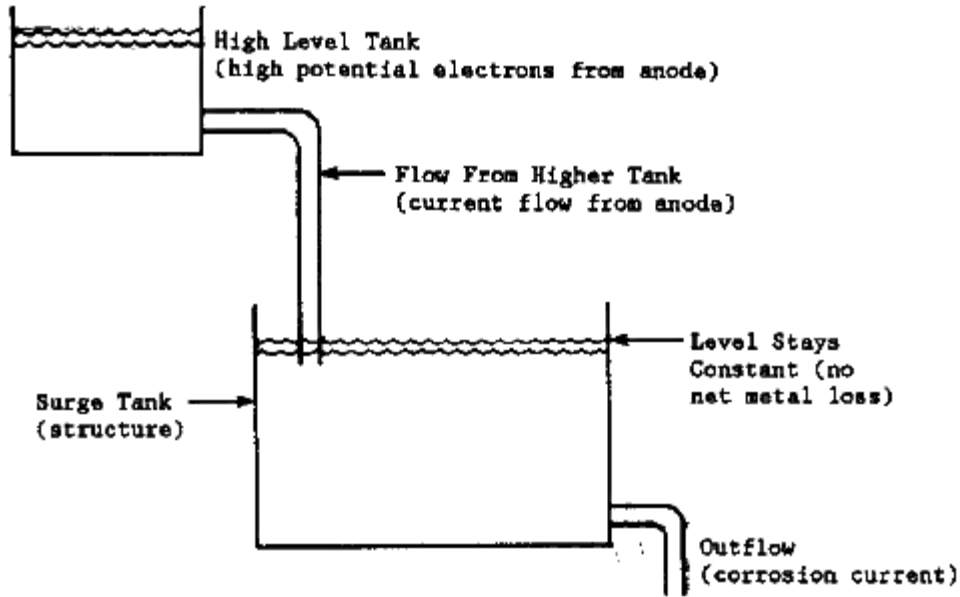
Figure 3

Cathodic protection cell

Figure 4

Hydraulic analogy of cathodic protection

protective coatings and electrical insulation. These regulations provide excellent guidelines for the application of cathodic protection to buried and submerged pipelines. Due to the safety and environmental consequences of system failure, there are also increasing numbers of federal, state, and local governmental regulations regarding the storage and transportation of certain materials that require corrosion control. Many of these regulations either make the application of cathodic protection mandatory on existing facilities as a primary means of corrosion control or allow it to be selected as a means for the mandatory control of corrosion on new facilities.

1.3.2 FUNCTIONAL REQUIREMENTS FOR CATHODIC PROTECTION. In order to be technically feasible, cathodic protection requires that the protected structure be electrically continuous and immersed in an electrolyte of sufficient volume to allow the distribution of current onto the structure.

1.3.2.1 CONTINUITY. Electrical continuity of the structure to be protected may be through metallic continuity provided by bolting, or welding of the structure. Continuity is often achieved or insured by means of electrical connections installed specifically to insure the effectiveness of cathodic protection. These connections are commonly called "bonds."

1.3.2.2 ELECTROLYTE. The electrolyte is commonly water or the water contained in moist earth. The conductivity of the electrolyte is an important factor in the determination of the need for cathodic protection and in the design of cathodic protection systems.

1.3.2.3 SOURCE OF CURRENT. Cathodic protection also requires the presence of a source of electrical current at the proper voltage or potential to prevent attack on the structure. These sources of current are commonly called "anodes." As described below, the anodes may be fabricated from an active metal such as magnesium, or zinc which provides a high potential source of electrons through corrosion on its surface. The anodes may also be fabricated from a relatively inert material which has the ability to pass current from its surface without being consumed at a high rate but which requires the use of an external energy source to increase the potential of the electrons supplied to the structure being protected. Anodes made from active metal are commonly called "sacrificial" or "galvanic" anodes, as the anode material is sacrificed to protect the structure under protection. The inert anodes are commonly called "impressed current" anodes as the external energy source is used to impress a current onto the structure under protection.

1.3.2.4 CONNECTION TO STRUCTURE. The anodes must be electrically connected to the structure through a metallic connection in order to complete the circuit of the electrochemical cell responsible for the protection of the structure.

1.4 SACRIFICIAL ANODE SYSTEMS. Cathodic protection in the sacrificial anode system is essentially a controlled electrochemical cell (see Figure 5). Corrosion on the protected structure is shifted to the anode. The anode is consumed in the process but is designed and installed so that it is easily replaced when consumed. Anode life of 10 to 15 years is common. Anode life is dependent upon the amount of current emitted by the anodes and their size. If the cathodic protection system is properly designed and installed, and if it is properly maintained (including periodic replacement of anodes as necessary), the structure being protected is essentially immune to corrosive attack and its lifetime is limited by other factors such as mission requirements or mechanical damage.
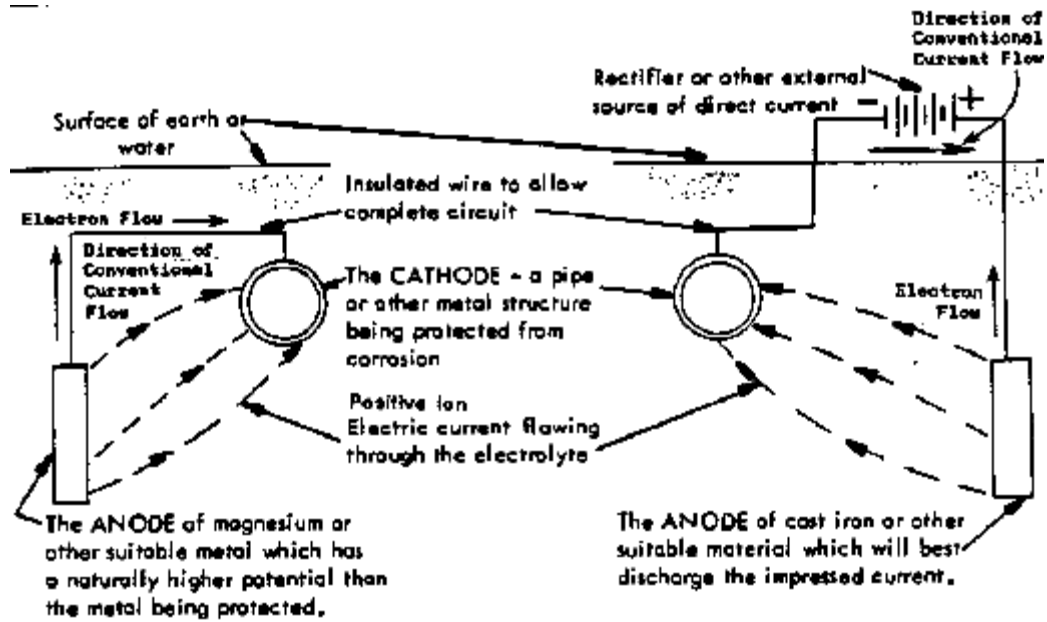
Figure 5

Sacrificial anode cathodic protection

and

Impressed current cathodic protection

1.4.1 ANODE MATERIALS. The materials used for sacrificial anodes are either relatively pure active metals such as zinc or magnesium, or alloys of magnesium or aluminum that have been specifically developed for use as sacrificial anodes. In applications where the anodes are buried, a specific chemical backfill material surrounds the anode in order to insure that the anode will produce the desired output.

1.4.2 CONNECTION TO STRUCTURE. Sacrificial anodes are normally supplied with either lead wires or cast-in straps to facilitate their connection to the structure being protected. The lead wires may be attached to the structure by welding or mechanical connections. These should have a low resistance and should be insulated to prevent increased resistance or damage due to corrosion. Where anodes with cast-in straps are used, the straps should be welded directly to the structure if possible, or, if welding is not possible, used as locations for attachments using mechanical fasteners. A low resistance mechanically adequate attachment is

required for good protection and resistance to mechanical damage. Welded connections are preferred to avoid the increase in resistance that can occur with mechanical connections.

1.4.3 OTHER REQUIREMENTS. As for all systems to be protected, the structure being protected by sacrificial anodes must be electrically continuous. The system should also include test stations that are used to monitor the performance and to adjust the system for proper operation. As in all mechanical and electrical systems, cathodic protection systems require periodic inspection, maintenance, and adjustment for satisfactory operation.

1.5 IMPRESSED CURRENT SYSTEMS. From the standpoint of the structure being protected, cathodic protection using the impressed current method is essentially the same as in the sacrificial anode system. As shown in Figure 5, the cathodic protection system supplies high energy electrons to the structure being protected and the circuit of the electrochemical cell is completed through the soil. However, in the impressed current system, a supply of direct electrical current is used to develop the potential difference between the anode and the structure being protected. Consumption of the anode is not the driving force for the flow-protective current. A properly designed, installed, and maintained impressed current cathodic protection system is as effective as the galvanic anode type of system in preventing corrosion of the structure being protected.

1.5.1 ANODE MATERIALS. The materials commonly used for impressed current cathodic protection have the capability of passing a current into the environment without being consumed at a high rate. Graphite and high silicon cast iron are the most commonly used impressed current cathodic protection anode materials; however, other materials such as magnetite, platinum, and newly developed oxide coated ceramic materials have been successfully used. For buried anodes, a backfill consisting of carbonaceous material is normally used: to decrease the electrical resistance of the anode; to provide a uniform, low resistivity environment surrounding the anode; and to allow for the venting of gasses produced at the anode surface.

1.5.2 DIRECT CURRENT POWER SOURCE. The supply of direct electrical current used to develop the potential difference between the anode and the structure being protected is normally a rectifier which changes alternating current to direct current of the appropriate voltage and current output. However, in special applications, other direct current power sources such as solar cells, thermoelectric cells, motor-generator sets, and wind-driven generators may be used.

1.5.3 CONNECTION TO STRUCTURE. Impressed current cathodic protection anodes are normally supplied with integral lead wires. In impressed current cathodic protection systems, the anodes are connected to the positive terminal of the rectifier and a wire connection is made between the negative terminal of the rectifier and the structure to be protected. The lead wires are connected to the cathodic protection system by welding or mechanical connections. These should have a low resistance and should be insulated to prevent increased resistance or damage due to corrosion. In applications where multiple anodes are used, the individual anode lead wires are often attached to a larger header cable which is connected to the rectifier. As the wire between the rectifier and the anode is under a high positive potential, very rapid attack of the wire will occur where there is a break in the wire insulation and the wire comes in direct contact with the electrolyte. The insulation on this cable is very critical and high quality insulation and care in installation is required for this application.

1.5.4 OTHER REQUIREMENTS. As for all systems to be protected, the structure being protected by impressed current must be electrically continuous. The system should also include test stations which are used to monitor the performance and to adjust the system for proper operation. As in the case of sacrificial anode systems, impressed current cathodic protection systems require periodic inspection, maintenance, and adjustment for satisfactory operation.

2. CRITERIA

2.1 INTRODUCTION. Various methods are available for determining whether the structure to be protected is being effectively protected through the application of cathodic protection. The technical basis for corrosion and cathodic protection is electrochemical. Electrochemical methods of determining the effectiveness of cathodic protection systems are the most widely used criteria for establishing the adequacy of the protection. In addition to electrochemical methods, inspections to determine the actual condition of the structure being protected can be used to determine whether or not effective protection has been achieved in the past. If there is no attack of the protected system in an aggressive environment, then the protective system has been functioning adequately. For buried or submerged systems where access is restricted, the electrochemical criteria are most widely applied.

2.2 ELECTRICAL CRITERIA. For submerged and buried structures, criteria based upon the electrochemical potential of the surfaces of the structure to be protected are the most widely used criteria for determining whether or not the structure is being effectively protected. In making these electrochemical potential measurements, as shown in Figure 6, a high impedance voltmeter is used to measure the difference in potential between the structure and a reference electrode placed in contact with the electrolyte. For buried structures, the copper/copper sulphate reference electrode is the reference electrode most commonly used for this purpose. For structures submerged in seawater the silver/silver chloride reference electrode is commonly used. Other reference electrodes can be used when appropriate. Potential readings obtained using any given reference electrode can be related to readings obtained with other reference electrodes. In order to the assure that the potential readings obtained are properly interpreted, the reference electrode used should always be noted. Readings should be reported as "XX.XX V versus YYY" where YYY is the reference electrode used to measure the structure potential. As these potential measurements are most commonly used to measure the potential of buried pipelines they are commonly called "pipe-to-soil potentials" even though they may refer to the wall of a water storage tank in contact with potable water. The more precise term for these measurements is "structure-to-electrolyte potential."

2.3 INTERPRETATION OF STRUCTURE-TO-ELECTROLYTE POTENTIAL READINGS. In order to determine whether or not a given surface is being adequately protected, structure-to-electrolyte measurements are taken at various locations surrounding the structure. Based upon a combination of corrosion theory, experimental and laboratory tests, and more importantly, upon actual field experience with a large number of protected structures, criteria for interpreting these structure-to-electrolyte potentials have been developed.

2.3.1 NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE) Standard RP-01-69. The most widely used criteria for evaluating structure-to-electrolyte potentials have been included in the NACE Standard RP-01-69, Recommended Practice for Control of External Corrosion on Underground or Submerged Piping Systems.
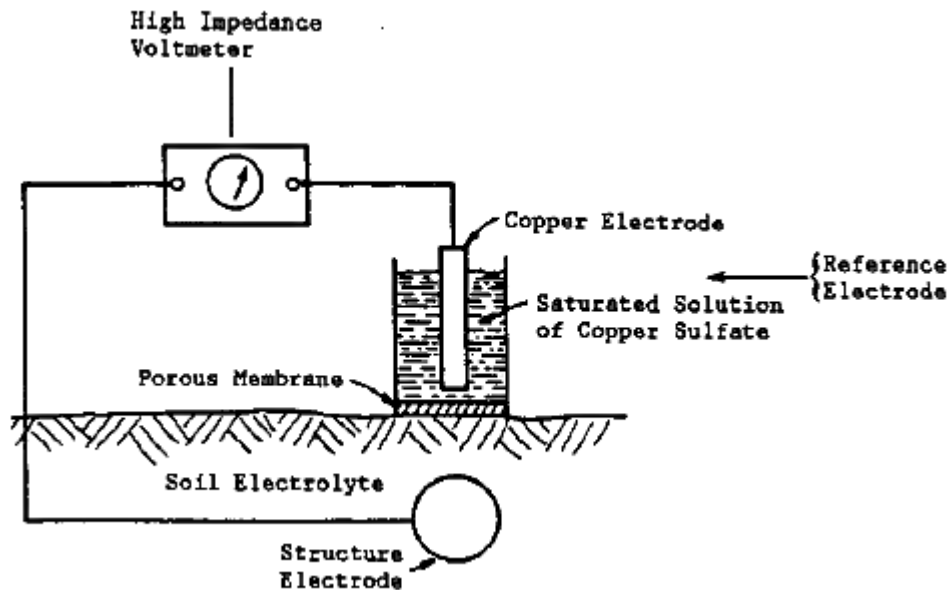

Figure 6

Structure to electrolyte potential measurement

2.3.1.1 CRITERIA FOR STEEL. The criteria options for the cathodic protection of steel and cast iron in soil and water are as follows:

a) -850 mV or more negative with respect to a copper/copper sulfate reference cell. This potential is measured with the protective current applied. For valid interpretation, the potential measurements must be corrected for IR drop through the electrolyte and metallic paths.

b) 100 mV or greater negative polarization shift measured between the pipe surface and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion.

c) A potential at least as negative as the potential established by the E log I curve method.

d) A net protective current from the electrolyte into the surface of the structure as determined by an earth current technique.

2.3.1.2 CRITERIA FOR ALUMINUM. 100 mV or greater negative polarization shift (refer to para. 2.3.1.1).

PRECAUTIONARY NOTE

Excessive Voltages: If cathodically protected at voltages more negative than -1.20 V measured between the structure surface and a saturated copper-copper sulfate reference electrode contacting the electrolyte and compensated for the voltage (IR) drops other than those across the structure-electrolyte boundary, may suffer corrosion as the result of the build-up of alkali on the metal surface. A voltage more negative than -1.20 V should not be used unless previous test results indicate no appreciable corrosion will occur in the particular environment.

Alkaline Soil Conditions: Since aluminum may suffer from corrosion under high pH conditions and since application of cathodic protection tends to increase the pH at the metal surface, careful investigation or testing should be made before applying cathodic protection to stop pitting attack on aluminum structures in environments with a natural pH in excess of 8.0.

2.3.1.3 CRITERIA FOR COPPER. 100 mV or greater negative polarization shift

(refer to para 2.3.1.1).

2.3.1.4 CRITERIA FOR DISSIMILAR METAL STRUCTURES. A negative potential equal to that required for the most anodic materials should be maintained. The potential should not exceed the maximum allowable potential for any material (such as for aluminum) in the system.

2.3.2 OTHER ELECTRICAL CRITERIA. Criteria evaluation of the structure-to- electrolyte potentials on other materials have been developed but are not included in NACE RP-01-69. The same measurement techniques and precautions are applicable to these criteria as for those in NACE RP-01-693.

2.3.2.1 CRITERIA FOR LEAD. Criteria for lead shall be as follows:

a) -750 mV or more negative with respect to a copper/copper sulfate reference cell. This potential is measured with the protective current applied.

b) 100 mV or greater negative polarization shift measured between the pipe surface and a stable reference electrode contacting the electrolyte.

NOTE: With the same precautions regarding potentials over 1.2 V and contact with alkaline soils as those for aluminum.

2.3.2.2 NACE RP-02-85. Criteria for the interpretation of structure-to-electrolyte potentials on storage tanks are given in NACE RP-02-85 Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems. The criteria in this recommended practice refer to the protection of steel structures and are essentially the same as in NACE RP-01-69.

2.4 FAILURE RATE ANALYSIS. Corrosion damage, as measured by frequency of system failure, usually increases logarithmically with time after the first occurrence of corrosion

failure. When effective cathodic protection is applied to a structure which has experienced corrosion damage, the frequency of failures will be significantly reduced. However, due to the presence of existing corrosion damage, the failure rate will not immediately be reduced to zero. Mechanical damage and previously undetected corrosion related damage may still result in failure, but if effective cathodic protection is achieved, corrosion failures should cease after a period of 1 or 2 years. Accurate failure records should be kept for both protected and unprotected systems in order to determine the need for cathodic protection and the effectiveness of installed systems. A typical failure rate analysis is shown in Figure 7.

2.5 NONDESTRUCTIVE TESTING OF FACILITY. Periodic evaluation of the condition of the protected system can also be used to determine the adequacy of the cathodic protection system installed on the structure, or to establish the need for protection.

2.5.1 VISUAL ANALYSIS. If the surface of a structure is accessible or is exposed for repairs, alterations, or specifically for the purposes of inspection, visual inspection may be used to evaluate the need for protection of the effectiveness of cathodic protection applied to the structure. Signs of corrosion such as the presence of corrosion products, pitting, cracking, reduction in physical size, or other evidence of deterioration should be noted.
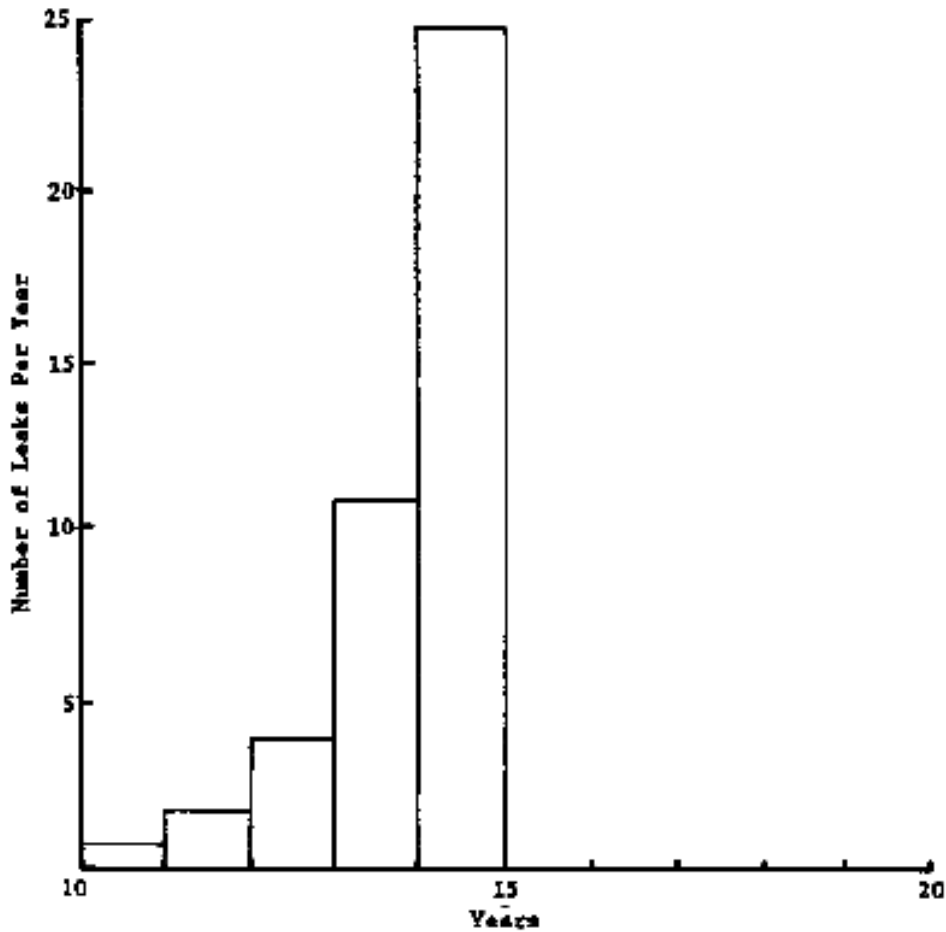
Figure 7

Failure rate versus time

A variation of visual inspection is the installation of small metal samples, or coupons, electrically connected to the structure at various critical points on the structure. Periodic removal and evaluation of these samples including visual observation and weight loss can be used to infer the corrosion activity of the structure being monitored.

2.6 CONSEQUENCES OF UNDERPROTECTION. If the measured potentials of a structure are not as negative as required by one or more of the applicable criteria for cathodic protection, some corrosion of the structure may occur. However, the corrosion of the structure will be reduced in proportion to amount of current supplied. When protective currents are totally interrupted, corrosion will usually return to a normal rate after a short period of time.

2.7 CONSEQUENCES OF OVERPROTECTION. In addition to the chemical corrosion damage that can occur on aluminum and lead structures if limiting potentials are exceeded in the negative direction, excessive negative potentials can also damage other metals. In addition to being wasteful of anode material or electrical power, excess potentials can cause disbondment of protective coatings and can cause hydrogen embrittlement of certain types of steels, especially high strength steels.

2.7.1 COATING DISBONDMENT. Excess cathodic protection potentials can result in the generation of hydrogen gas. When the cathodic protection potential reaches the polarized potential of -1.12 V (instant off), with respect to a copper/copper sulfate reference electrode, the generation of hydrogen gas will occur. When hydrogen gas is generated it is often trapped between the coating and the surface and causes blisters and disbonding of the coating. Electrolyte can subsequently fill the gap between the coating and the metal and, as the coating is an electrical insulator, sufficient current for effective cathodic protection cannot reach the affected area and corrosion will occur. Coating disbondment is a particular problem in water tanks. In soil environments when high quality coatings are used, disbondment is seldom encountered at potentials less negative than -1.6 V (current on) or -1.12 polarized potential (instant off).

2.7.2 HYDROGEN EMBRITTLEMENT. The hydrogen produced when cathodic protection currents are excessive can also result in the reduction of the ductility of steel. This is particularly true for high strength steels (in excess of 130,000 pounds per square inch (psi) yield strength).

3. PRECAUTIONS

3.1 INTRODUCTION. Cathodic protection systems depend upon the application of electrical currents to counterbalance the natural tendency of metals to revert to their low energy combined states. In addition to the hazards involved with the operation of any electrical device, cathodic protection systems may, through the flow of current in undesirable paths, accelerate the corrosion of other structures in the vicinity of the structure being protected. Potentials exceeding those recommended can result in system damage. Potentials less than those required for complete protection usually result in some protection on most areas of the structure and do not result in attack at rates greater than for completely unprotected structures of similar materials and conditions.

3.2 EXCESSIVE CURRENTS AND VOLTAGES. Flow of current in undesirable paths is proportional to the total amount of current flowing in the cathodic protection system, all other factors being equal. Thus, protection of well coated structures that require small amounts of current for protection will cause fewer problems than protection of poorly coated or bare structures that require substantially more current. Assuming that damaging potential levels such as those resulting in coating damage or hydrogen embrittlement are not reached, excessive currents will not cause deterioration of the structure being protected but can cause severe localized attack of adjacent structures.

3.2.1 INTERFERENCE. The flow of current in undesirable paths resulting in accelerated attack of adjacent structures is called "interference." The adjacent structures are commonly called "foreign" structures. In Figures 8 and 9, the mechanisms of two typical situations resulting in interference are illustrated. In Figure 8, the undesired current flows through two buried pipelines in the vicinity of the protected system. Corrosion is accelerated at locations where positive ions are forced to enter the environment from the metal surfaces. Although corrosion is not usually accelerated on the protected structure, cathodic interference can disturb the desired current distribution on the structure being protected and can reduce the amount of protection being received in some areas to a level below that required for complete protection. Corrosion occurs where the current leaves the structure and enters the electrolyte. In some

models of electricity, the flow of positive ions in the electrolyte is used to establish the flow of imaginary positive charges in the metallic path used to describe conventional "current flow." However, conventional current flow is widely used in the cathodic protection industry and the flow of ions (positive) through the electrolyte should be described for each situation in order to avoid confusion. This description of electron and ion flow will be used throughout to explain what is actually happening. In Figure 9, the potential gradient surrounding an impressed current anode results in an electron flow along a foreign structure. This flow is described as positive ion (conventional) current flow from the anode, through the electrolyte, to the pipe (cathode) and continuing on along the pipe (imaginary) to the point of discharge (anode area) where accelerated corrosion occurs.
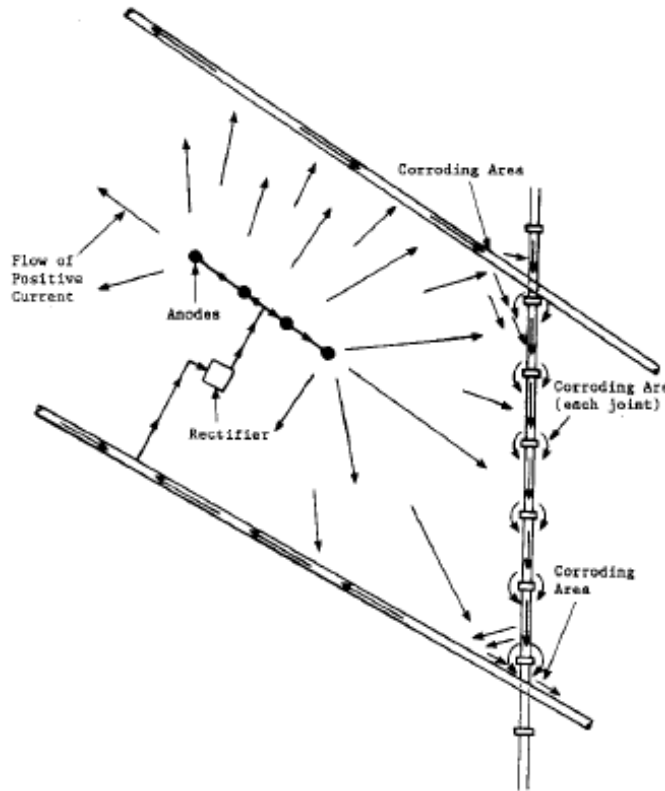
Figure 8

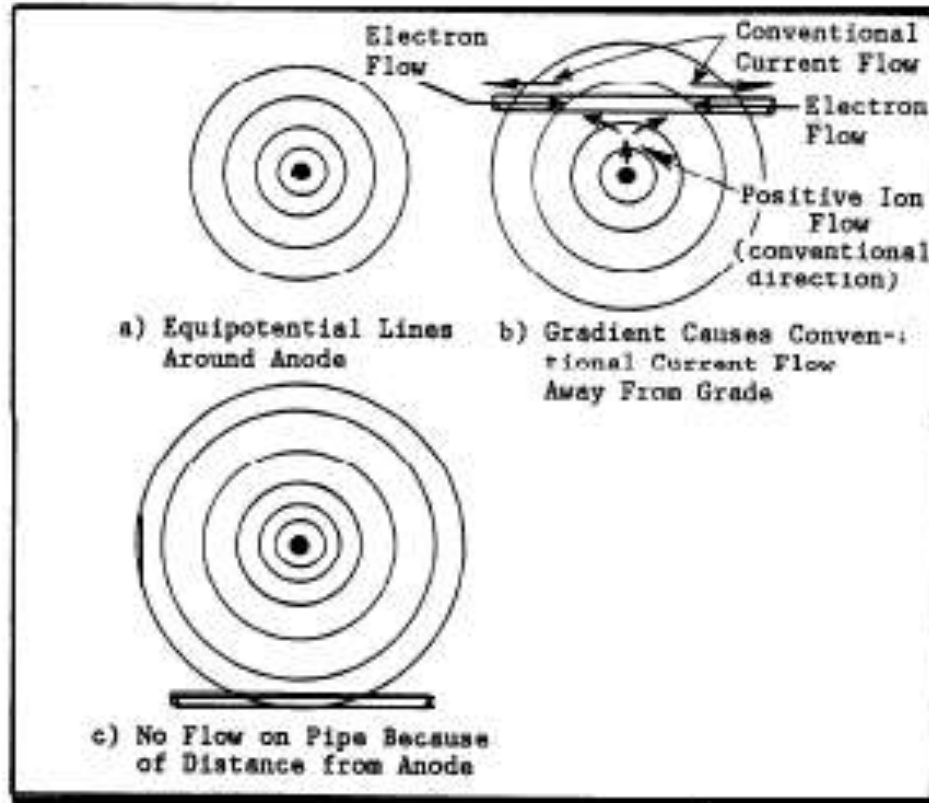Interference from impressed current cathodic protection system

Figure 9

Interference due to potential gradients

3.2.1.1 DETECTING INTERFERENCE. Cathodic protection interference problems are most commonly detected through the measurement of structure-to-electrolyte potentials and by the measurement of current flowing along a structure by measuring the potential (IR) drop caused by the flow of the current through the resistance of the structure. Interference is most commonly detected during the measurement of structure-to-electrolyte potential measurements. Figure 10 shows a typical situation where interference is occurring and shows locations where structure-to-electrolyte potentials have been measured. Table 1 shows the potential measurements, which are also plotted in Figure 11. As can be seen in Figure 12, the location of the foreign structure can be easily determined by its influence on the protected structure. Likewise, the measurements taken on the foreign structure clearly show the areas where the ions are picked up and discharged.
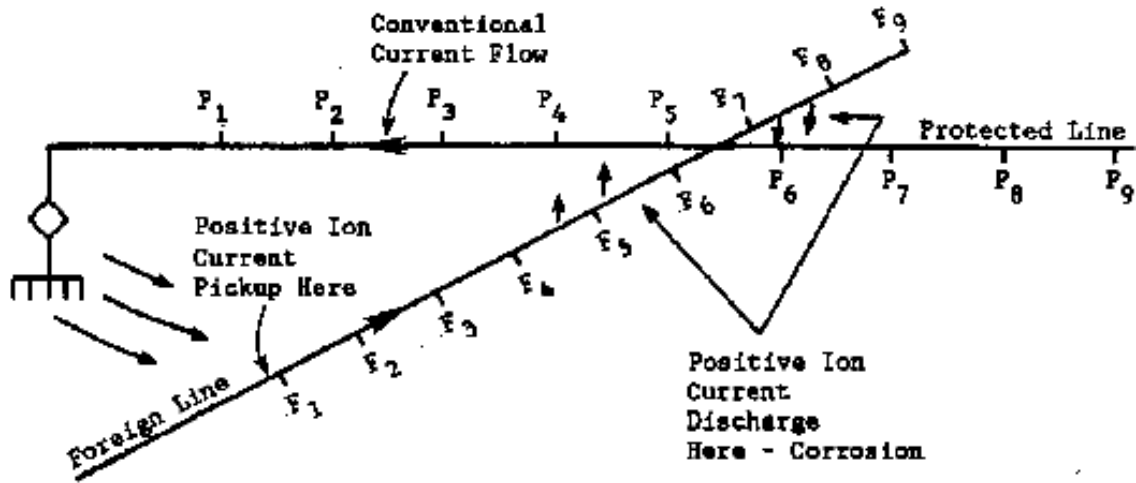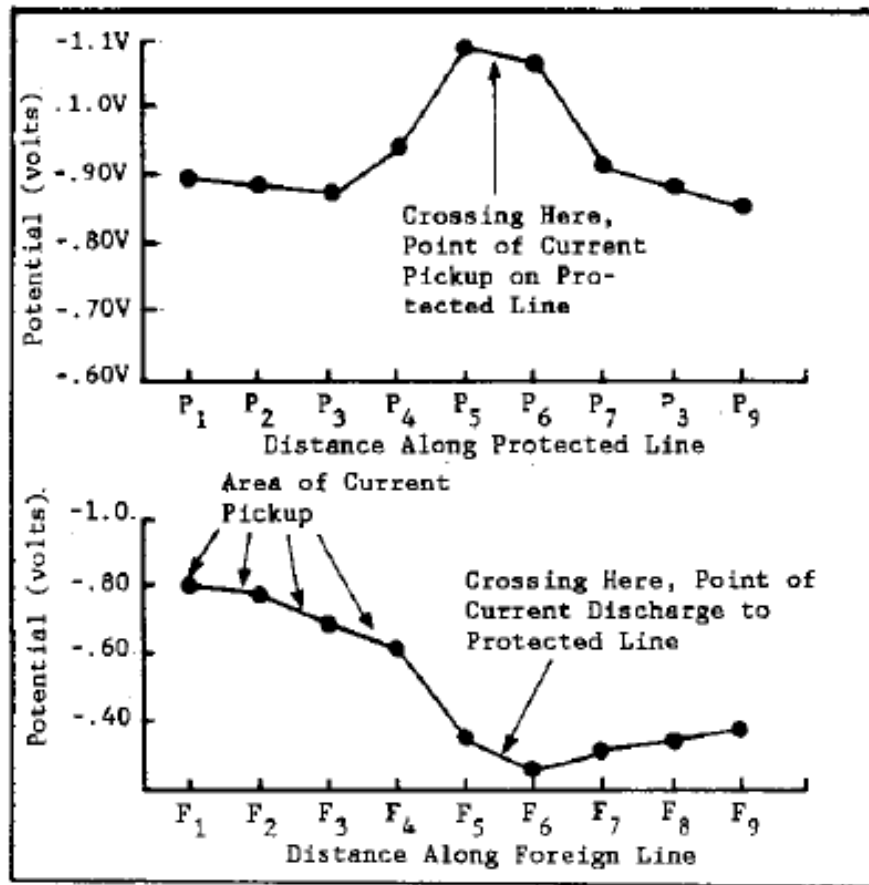
Figure 10

Interference testing

Figure 11

Plot of potentials from interference test

TEST POINT	POTENTIAL VERSUS COPPER/COPPER SULFATE (V)	TEST POINT	POTENTIAL VERSUS COPPER/COPPER SULFATE (V)
P1	-0.883	F1	-0.832
P2	-0.876	F2	-0.810
P3	-0.864	F3	-0.765
P4	-0.927	F4	-0.746
P5	-1.058	F5	-0.421
P6	-1.012	F6	-0.386
P7	-0.881	F7	-0.405
P8	-0.854	F8	-0.413
P9	-0.836	F9	-0.419

Table 1

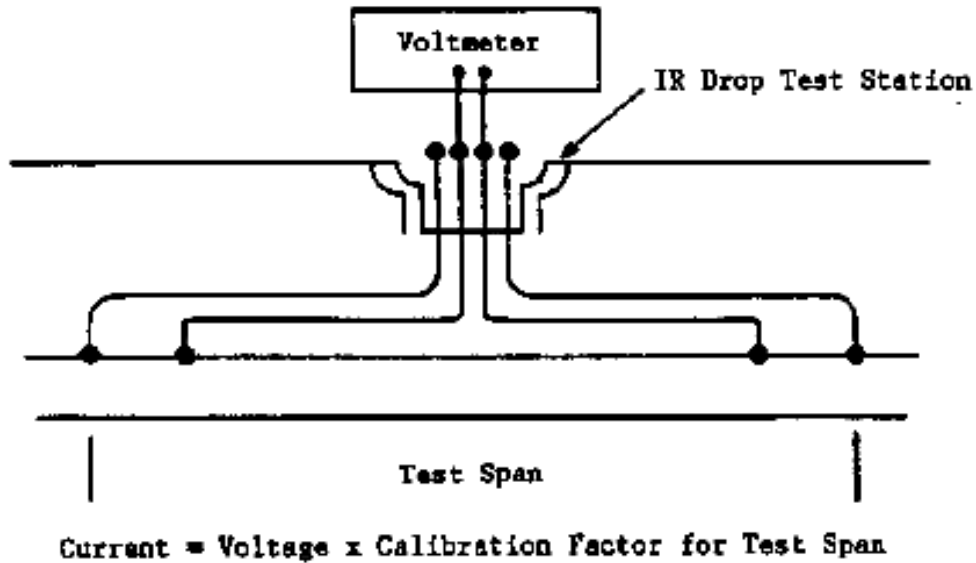Results of structure-to-electrolyte potential measurements

Figure 12

Measurement of current flow in structure

Another field measurement associated with interference is the measurement of the current flowing through a structure. As shown in Figure 12, the procedure involves the measurement of the potential drop along a section of the structure which is carrying the current. The section of structure is initially calibrated by passing a known current through the section using the outer set of test leads. Subsequent measurements of the potential drop are then referred to the calibration factor for the structure and the current is calculated. This measurement is called an IR drop test. Test stations are commonly installed on long pipelines to measure the current

flowing in them in order to detect changes in the current which could be an indication of either interference or problems with the cathodic protection system on the pipeline.

3.2.1.2 CONTROL OF INTERFERENCE - ANODE BED LOCATION. The single most important factor in controlling interference is the location of the anode bed. In general, the remote anode beds commonly used in impressed current cathodic protection systems cause more problems with interference than do sacrificial anode systems where the anode-to-structure distances are usually in the order of 10 feet or less and the driving potential is small (1 V or less). The influence on foreign structures should be a primary consideration in the location of remote anode beds.

3.2.1.3 CONTROL OF INTERFERENCE - DIRECT BONDING. One method of correcting interference is to bond the foreign structure to the protected structure. The bonding can either be a direct low-resistance connection or a resistive bond. Figure 13 shows correction of an interference problem by direct bonding. Bonding both pipes together, essentially makes both pipes the protected line. A test station is usually installed at such a location in order to either verify the continuity of the bond, or to measure the current flowing through the bond. To allow for future bonding and testing, a bond station should be installed wherever pipelines cross and at other locations where interference is possible.
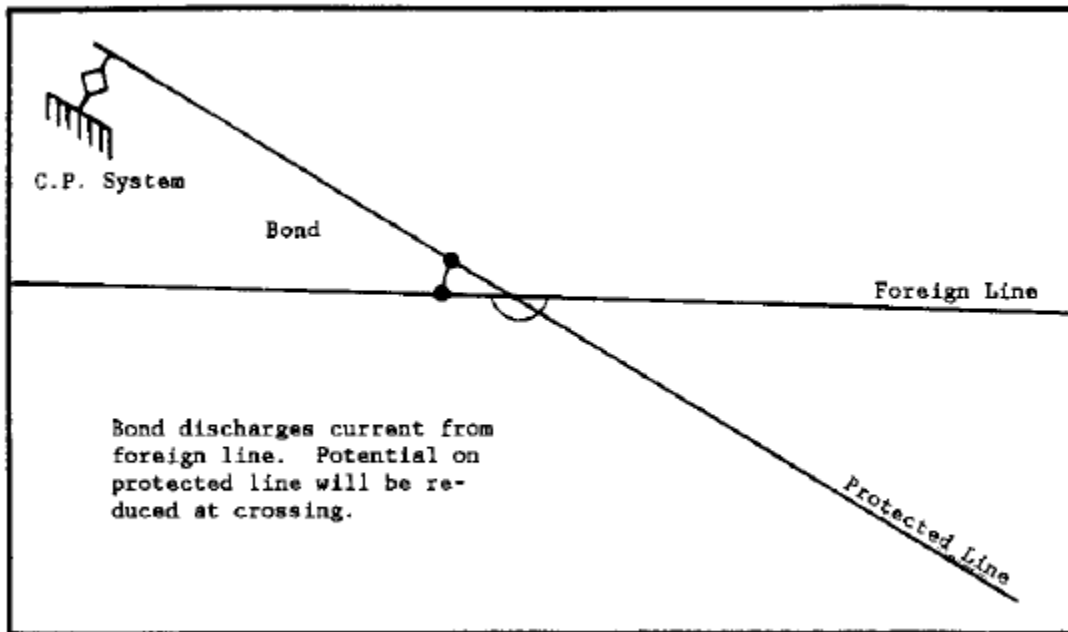
Figure 13

Correction of interference – direct bonding

3.2.1.4 CONTROL OF INTERFERENCE - RESISTIVE BONDING. Direct bonding is often not desirable either because the existing cathodic protection system cannot supply enough current to protect both structures, or the foreign structure is not owned by the same organization as the one supplying the current and reducing the current flowing to the foreign structure to minimum levels is desired. In this case, a resistive bond is installed between the structures and adjusted to supply only the correct amount of current to the foreign structure to bring its potential to the same level as it would have been without the protected structure in the vicinity. Figure 14 shows such an installation and Figure 15 shows the potentials measured on both structures. Test stations are normally installed where resistive bonds are used in order to facilitate testing of the corrective action and adjustment of the resistor. The resistor may either be a commercially supplied wire wound adjustable resistor of the proper resistance and current rating or may be fabricated from nichrome resistance wire cut to suitable length in the field and wound into a coil.

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        Adjustment of the resistor to correct the interference is
determined by installing a temporary resistive bond and measuring the current
through the resistor and the changes in potential achieved by the temporary
bonding.  The correct value for the bond current can be approximated from
these measurements by using the following formula:

        ▲Et/Id  =  ▲Er/It  and  It  =  (▲Er x Id)/▲Et

where

        It   =  correct value of bond current
        Id   =  current through temporary bond
        ▲Er  =  E fn - E fr = change in potential required to clear
                interference
        ▲Et  =  E fn - E frd = change in potential caused by temporary bond
        E fn =  natural potential of foreign structure
        E fr =  potential of foreign structure with no bond
        E frd =  potential of foreign structure with temporary bond
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Figure 14

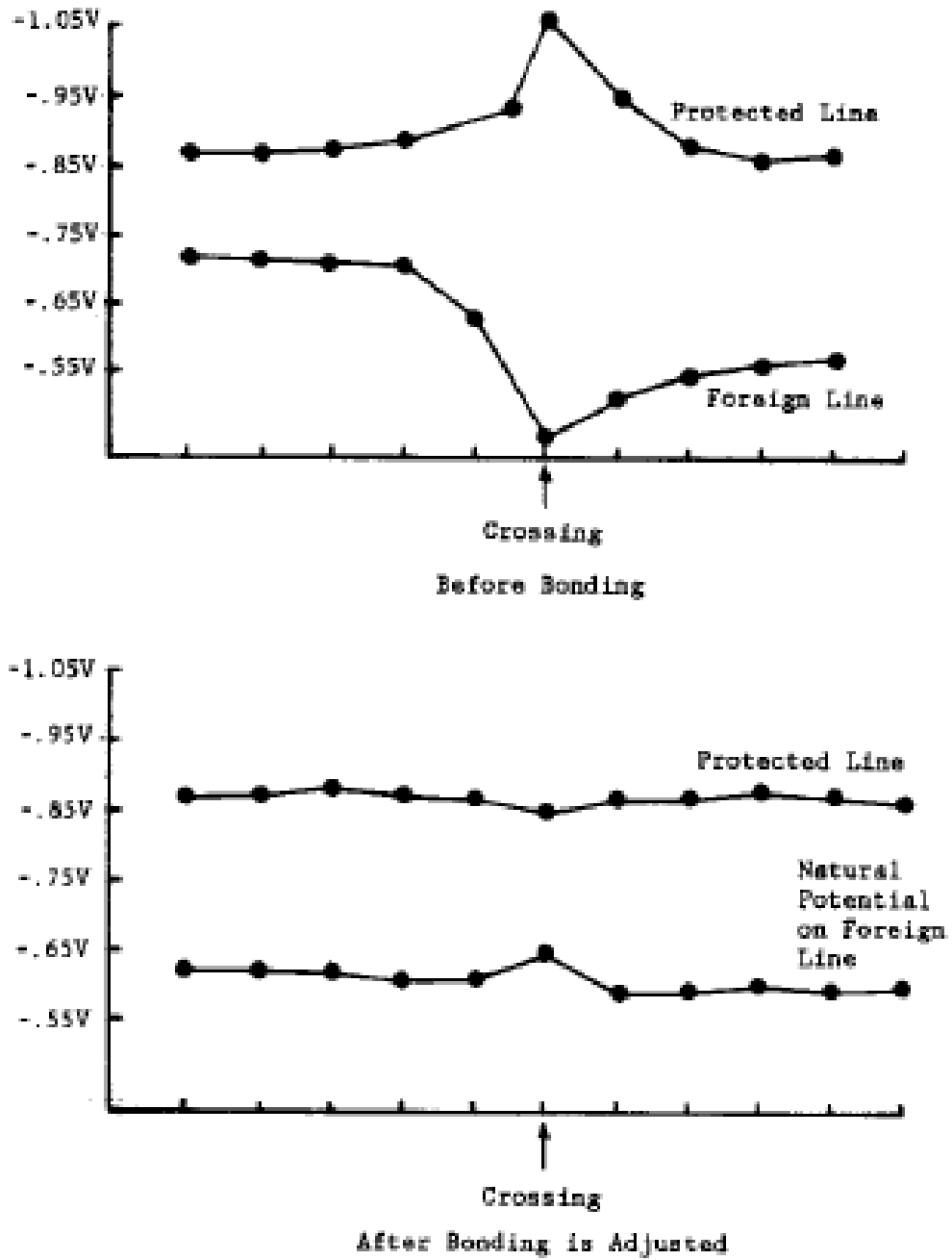Correction of Interference - Resistive Bonding

Figure 15

Effects of bonding on interference test potentials

For a permanent bond, the resistor is adjusted while measuring the potential of the foreign line at the crossing. The amount of resistance is correct when the foreign line potential is equal to E fn (natural potential). Bonding, as shown in Figure 16, is also used to insure continuity of buried structures both for the prevention of interference and for the proper operation of cathodic protection systems.

3.2.1.5 CONTROL OF INTERFERENCE - SACRIFICIAL ANODES. In some cases, the method used to control interference is to install a sacrificial anode on the foreign structure. This could bring the potential of the foreign structure in the vicinity of the protected structure to the same or higher potential as the protected structure at the crossing, providing current to the foreign line in the opposite direction as the interference current. If the foreign line is well coated the magnesium anode may negate all interference current. If the foreign line has poor coating or is bare and the interference is large, the anode at the crossing will reduce or negate the interference at the crossing, but interference current will still flow from the foreign line at each side of where the anode is connected. In summary, an anode on the foreign line at the crossing will help and in some cases completely cure the interference problem, but in other cases it will not completely solve the interference problem and a resistance bond may still be needed. Use of a sacrificial anode to control interference is shown in Figure 17. The anode should be sized to provide a current in excess of the required bond current.

3.2.2 EFFECTS OF HIGH CURRENT DENSITY. Excessive current density can result in hydrogen embrittlement or coating disbondment. In many cases, improper location of the ground beds in an impressed current system or interference from foreign structures can result in uneven current distribution on the protected structure. In order to achieve protective potentials in some areas of the structure, excessive potentials are experienced in other areas of the structure. This situation can be corrected by installing additional anodes or relocating the anode bed to achieve a more even current distribution. In some cases, the structure can be separated into sections and the current distribution improved by the installation of resistive connections between the structure and the rectifier. Excessive potentials are seldom experienced in sacrificial anode systems but if experienced can usually be corrected through the installation of resistors in selected anode lead wires.

3.2.3 EFFECTS OF ELECTROLYTE PH. Aluminum and lead should not be cathodically protected in some environments where the pH is greater (more alkaline) than 8.0. In tight soils such as clay, the alkali formed around the cathode by cathodic protection will increase the pH to very high levels and cause severe chemical attack on lead and aluminum. Where the electrolyte is water which is moving and exchanged, the alkali formed by cathodic protection can wash away and the adverse effects of cathodic protection on lead and aluminum are reduced. Some types of protective coatings, particularly the alkyds, can also be damaged by highly alkaline environments.
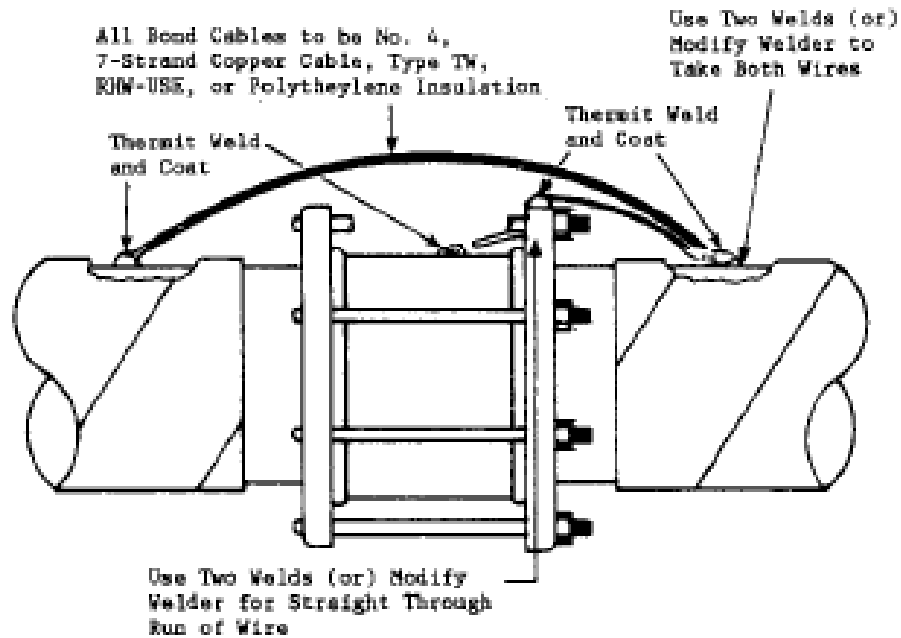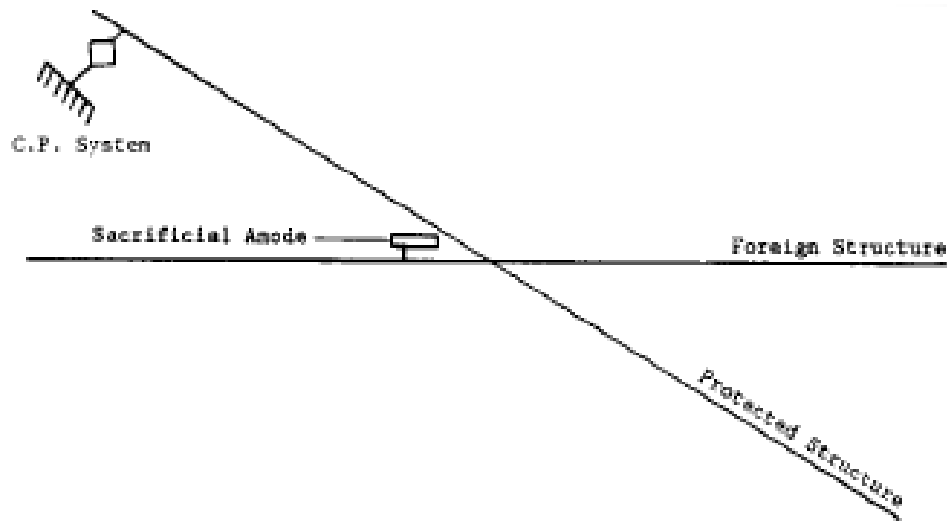

Figure 16

Bonding for continuity

Figure 17

Control of interference – sacrificial anode

Low pH (acidic) conditions can also cause problems with both corrosion and cathodic protection. In soils with a pH lower than 3.0, current density requirements for the protection of steel can be up to 10 times as high as those required for protection of steel in neutral soil. These excessive current requirements make cathodic protection in such environments difficult and costly. The use of high quality coatings in conjunction with cathodic protection in such environments is essential.

3.3 HAZARDS ASSOCIATED WITH CATHODIC PROTECTION. Cathodic protection systems, like all other electrical systems, can be dangerous under some circumstances. They can, however, be safely operated under most conditions if the proper precautions are taken in their design, installation, operation, and maintenance.

3.3.1 EXPLOSIVE HAZARDS. In areas where flammable liquids or explosive gasses may be present, consideration should be given to the proper design of both impressed current and sacrificial anode cathodic protection systems. Such areas include, but are not limited to, fuel storage farms, fuel terminals and fueling areas, refineries, ammunition depots, and manholes (sewer gas). As the protective currents used for cathodic protection flow through the environment without inherently causing arcing or appreciable resistive heating, cathodic

protection can be safely used in such environments. However, cathodic protection rectifiers to be used in such applications should be special oil-immersed explosion-proof types, or should be located outside of the hazardous area. In addition, all connections should be made in explosionproof housings. In addition to explosive liquid and gas situations, currents from impressed current systems can be picked up on blasting leads and could cause detonation of the blasting caps. Impressed current cathodic protection systems should be turned off whenever there is blasting in the vicinity.

3.3.2 BONDING FOR ELECTRICAL SAFETY. Electrical bonding is often required for safety where ships, vehicles, or aircraft are fueled or loaded. Any voltage gradient in the soil can result in a potential difference between structures located at different points. These potential differences can result in dangerous arcing. Cathodic protection systems can increase the level of such voltage gradients. The normal electrical bonding used in such circumstances is sufficient to mitigate this hazard. The voltage gradients produced by cathodic protection systems can also cause arcing when, during pipeline repairs, the pipeline is severed. A temporary bond installed across the pipeline before cutting should be used to prevent this hazard. Interference caused by docking a vessel in the vicinity of a cathodically protected pier or quaywall can cause accelerated attack on the vessel (see Figure 18). This problem is normally prevented by using a direct bond between the protected structure and the vessel (see Figure 19).
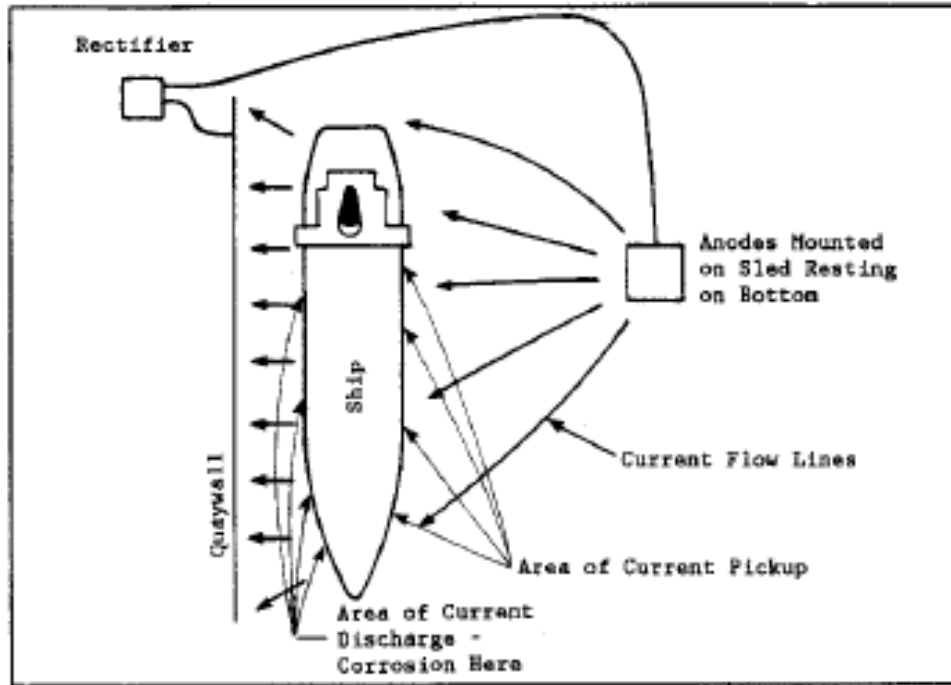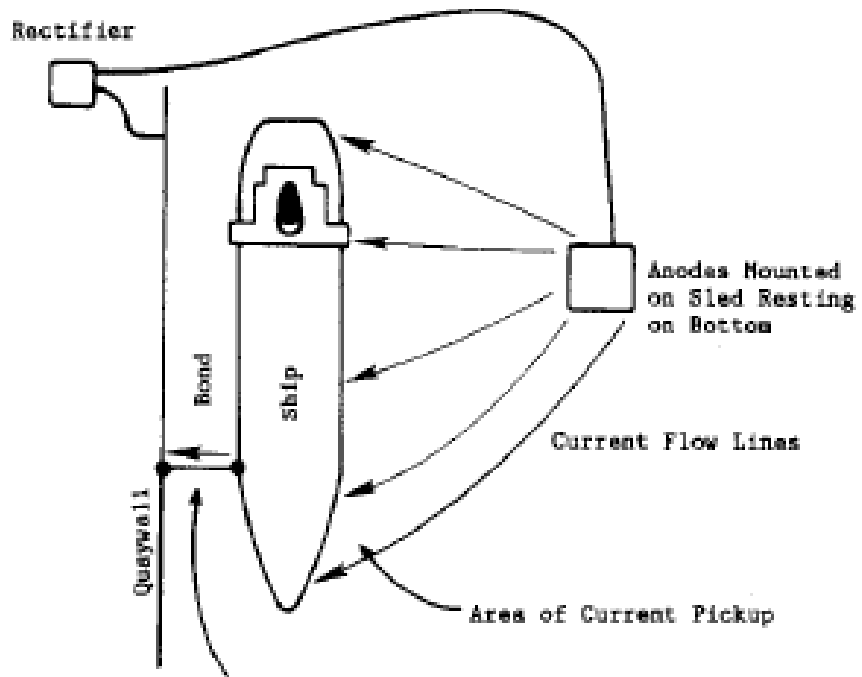
Figure 18

Interference due to cathodic protection of quaywall

3.3.3 INDUCED ALTERNATING CURRENTS. As is the case for any large structure in the vicinity of ac electrical transmission lines, ac can be induced on underground or aboveground components of cathodic protection systems, including the structure being protected. This is particularly true if the structure is well coated or isolated from the ground and is oriented parallel to the transmission lines. Pipelines using the same right of way as the transmission lines are particularly susceptible to induced ac voltages. In addition to causing corrosion damage, these voltages can be dangerous to personnel who may come in contact with the structure or cathodic protection system. The location of the ac transmission lines should be noted during the design of cathodic protection systems. The effects of induced currents and relocation of either the transmission line or the planned system should also be considered. Location of test station in areas where induced currents may exist should be particularly avoided. Induced currents should also be considered when performing cathodic protection field surveys or other electrical tests in the vicinity of ac transmission lines.

Figure 19

Correction of interference - bonding