Maintenance of Cathodic Protection Systems

by

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MAINTENANCE OF CATHODIC PROTECTION SYSTEMS

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INTRODUCTION:

The fundamental purpose of this paper is not to make the reader a corrosion engineer, but it is intended to make the reader aware of some of the aspects of corrosion and its prevention. Significant money can be saved through a few hours of simple maintenance, thereby increasing the useful life of underground metallic structures.

This section of the manual will discuss the practical aspects of maintaining cathodic protection on underground structures - what to monitor, how to monitor and how to determine the cause and the necessary corrective measures should any deficiencies be detected.

MAINTENANCE PROGRAM

The following items outline what types of measurements and data should be recorded for proper maintenance. The methods required to perform this maintenance are elsewhere in this manual.

Impressed Current System

Monthly

Rectifier Voltage

Rectifier Current

Verify proper rectifier operation

Within **6 months** of system installation and each year thereafter

Complete system inspection

Structure-to-soil potentials

Interference testing

Verify isolation and continuity

Re-perform previous "*6 months after Impressed Current installation testing*" **within 3 months** after any construction activity carried on within 3 feet of the underground pipeline or storage tank system.

Sacrificial System

Monthly

No action required

Within 6 months of system installation **and every 3 years** thereafter

Complete system inspection

Structure-to-soil potential measurements

Interference testing

Verify isolation and conductivity

Re-perform previous "*6 months after sacrificial system installation testing*" **within 3 months** after any construction activity carried on within 3 feet of the underground pipeline or storage tank system.

Overall

Perhaps the most important aspect of good maintenance techniques is record keeping. This cannot be stressed enough. Without proper record keeping, a maintenance program is essentially useless. Proper record keeping not only provides historical data for future cathodic protection design, it also often provides clues as to the source of a detected deficiency. For example, during an annual survey of a rectifier-protected underground storage tank system, potential measurements are about -8OOmv. This might indicate that the system is aging and that the rectifier current output should simply be increased. However, upon examining records, it is indicated that the current has not decreased over time, as would be expected in an aging system, but has actually increased slightly. Structure-to-soil potentials were previously -1200 mv, indicating some other area of failure. After some investigation, it was determined that a new air line installation was electrically shorted to the system. This short was easily removed and the protective levels were restored. This is a good example of how proper record keeping will identify or dismiss detected deficiencies.

Recording

The required record keeping for proper maintenance is relatively simple. The data may be obtained using computerized equipment or with standard test equipment.

TEST PROCEDURES

The purpose of the following section is to inform the reader in the measurements necessary and instruments used to monitor cathodic protection. Proper techniques as well as useful tips are discussed.

Potential Measurements

Purpose

To determine the potential difference between the subject structure and the soil environment.

Equipment

High Impedance (10 megohms minimum) digital voltmeter.

Copper/copper sulfate reference electrode.

Reel of wire containing at least 100 feet of insulated, stranded copper wire, minimum size #16 AWG.

Assorted clips and test leads.

Method (see Figure 1)

Attach a test lead from the negative terminal of the high impedance meter to the subject structure. Make sure electrical contact is good - scrape surface as required.

Connect the reference electrode to the positive terminal of the meter.

Place reference electrode on surface of soil as near to directly over the structure as possible. Obtain low resistant contact by pushing cell into ground.

Obtain reading on 2-volt DC scale.

If reading fluctuates, insure that there is solid contact to ground and to structure.

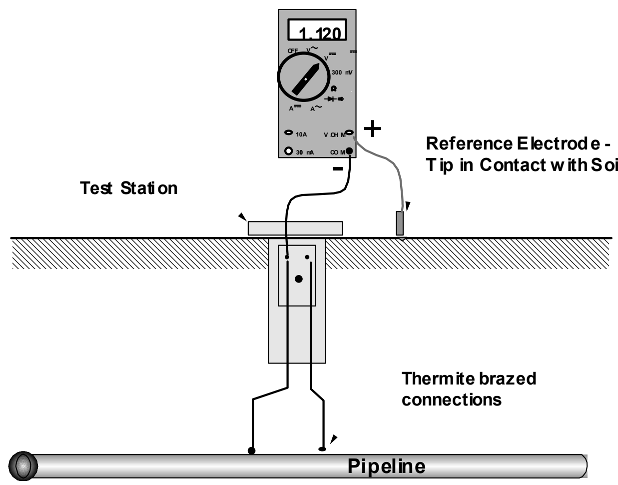


Figure 1 - Structure Potential Testing

Results

Record the measurement on the appropriate data sheet. Measurements taken in this manner are negative potentials.

Repeat procedure at representative locations along the structure being sure to accurately describe location on data sheet.

Notes:

Observing structure-to-soil potentials on structures that lie beneath large expanses of asphalt or concrete can be very inaccurate if taken through the asphalt or concrete. The electrode tip must be in contact with the earth over the tank or piping of concern. This may necessitate drilling permanent access holes to facilitate this measurement. Place the electrode in the test hole and observe the potential. If the meter reacts slowly, pour a small amount of water in the hole and repeat. When the meter reacts in a brisk normal manner, the reading will probably be valid.

When observing structure-to-soil potentials, the potential should remain steady. If the potential varies back and forth, a stray DC current may be indicated. Note the period of oscillation on the data sheets. If the reading appears to be vibrating, an AC stray is apparent. Record the possible presence of stray AC or DC current on the data tables.

The electrode should be placed directly over the structure or as near as possible when observing structure-to-soil potentials on all facilities.

Sometimes it is necessary to select a scale larger than two volts, especially if the reading is being observed near an anode. The 10-volt scale on the high resistance meter should then be used.

When measuring structure-to-soil potential measurements through frozen earth, contact can sometimes be made by first soaking the soil with warm water.

Dielectric Isolation and Continuity Testing

Purpose

To verify proper functioning of dielectric insulating flange kits, nylon bushings, and dielectric unions.

To verify electrical continuity in pipe, between tanks in a common excavation and between tanks and piping when continuity is required for effective cathodic protection.

Equipment

High Impedance (10 megohms minimum) Digital Voltmeter.

Copper/copper sulfate reference electrode.

Reel of wire containing at least 100 feet of insulated, stranded copper wire, minimum size #16 AWG.

AC Null Balance Resistance Meter

Assorted clips and test leads.

Fixed Cell - Moving Ground Method

Connect the reference electrode to the positive terminal of the voltmeter.

Place the reference electrode at a fixed location at the surface of the soil in the general area of the structures for which isolation or continuity is being tested.

Attach a test lead from the negative terminal of the high impedance voltmeter to a test prod or clip lead.

Make firm contact with one component of the structure for which continuity or isolation is being determined.

Obtain and record reading on 2 volt DC scale.

Make firm contact with a component of the other structure (or component) for which continuity or isolation is being determined.

Obtain and record reading on 2 volt DC scale.

Note: The two readings should be obtained with as little time as possible between each reading. The reference electrode must not be moved during the test period.

Results

For structure components which are isolated from each other, the potentials measured will be substantially different (greater than 3 - 10 millivolts).

For structures which are electrically continuous with each other, the potentials measured will be the same (no more than 1 millivolt difference in value).

For structures where the potential difference is between 2 and 5 millivolts, continuity or isolation is uncertain. Re-test using the Test Procedure provided in the AC Null Balance Resistance Method.

AC Null Balance Resistance Method

Using the AC Resistance meter, contact a component of the structure of concern using individual test leads from the P1 and Cl terminals of the meter.

With the same meter, contact the other structure (or component) of concern using two additional test leads connected to the P2 and C2 terminals of the meter.

Adjust the range selector switch and "Null-Balance" dial until the analog meter indicates a "zero" or balanced condition.

Observe and record the resistance measured between the two structures.

Results

For structures which are electrically continuous to each other, the resistance measured will be less than 0.5 ohms.

For structures which are electrically isolated from each other, the resistance measured will be greater than 2 ohms.

For structures where the values measured fall between 0.5 and 2 ohms, continuity or isolation is uncertain.

Note: Four individual leads from the meter to the structures of concern must be used for this test to be valid. In addition, individual contacts for each lead must be made to the structures being tested.

SURVEY & EVALUATION OF PROTECTED STRUCTURES

Potential Surveys

The structure-to-soil potential measurement is necessary to determine the effectiveness of cathodic protection on any underground metallic structure. A detailed potential profile of all protected structures should be performed at the intervals indicated in "Maintenance Programs". The survey techniques to be employed are outlined in "Test Procedures". All test points should be contacted and over-the-structure potential recorded. Subsequent to collecting the data, the criteria for cathodic protection as discussed in the "Criteria" section should be applied. If the structure is experiencing adequate protection, no further testing is required; if not however, the trouble shooting procedures should be followed.

Stray Currents

Stray current corrosion can cause serious corrosion when it occurs. Stray current is the result of current leakage from some electrical system such that part of the current path is through the earth. An underground metallic structure lying within the circuit will tend to receive and discharge current: the anodic areas correspond to points of current discharge. Currents of this sort are commonly known as "stray currents" because of their inherently accidental nature, and the damage they cause is referred to as "electrolytic corrosion".

The most common source of stray current is the electrical railway system or its urban counterpart, the streetcar or subway. Return current from the electrically conveyed vehicle system divides, part returns to the substation via the rails and part leaks off the rails, producing current flow through the soil. This leakage may be collected by an underground metallic structure. Near the substation, the current flows from the pipeline through the soil back to the rail system, causing corrosion of the structure. Installation of metallic bonds from the structure to the negative bus at the substation will avert damage to the structure by providing an alternate return path for the current.

There are other possible sources of stray current - almost any DC powered network is capable of causing damage in this manner. Mine railways, cranes, and other machinery using DC for operational power are potential hazards. Frequently there are severe exposures in and near chemical plants using electrolytic processes. Welding equipment, particularly when employed in production work, is a common source of trouble, although rarely is the damage done at any great distance from the equipment.

Another common source of stray DC earth currents are impressed current cathodic protection systems which can cause corrosion damage to foreign structures which are in the same area. Stray currents such as this are not the same type as describe above, but are usually classified as "cathodic interference". The damaging effect is altogether accidental, but the presence of DC in the earth is intentional. A complete discussion of cathodic interference is contained in the next section.

Whenever the measurement of structure-to-soil potentials show fluctuating values with no "rhyme nor reason", there is probably a case of stray current at hand. It is very helpful to leave the instrument connected and watch the fluctuations through several periods of change. The frequency and nature of the oscillations will often give a clue as to the origin. It may be that the actual operation of the offending system can be observed in the near vicinity.

Stray currents are normally very noticeable during a structure-to-soil potential survey. If the meter is left connected in the usual manner, it is sometimes even possible to observe potentials which fluctuate from negative to positive.

When location of the cause of trouble is not possible by direct observation, a recording instrument should be connected to the structure. The record over a twenty-four hour period can very often be useful in detecting the offender. For example, if there is a cessation of the fluctuation during the noon hour, then the source is most likely industrial machinery rather than transportation equipment. By the application of similar reasoning to such records of several successive days, it is usually possible to detect the DC system from which the stray current is emanating.

Cathodic Interference

A cathodic protection system installed to arrest corrosion on a given underground structure may produce extensive damage on other structures. Usually the structures concerned will be situated in close proximity to each other: they may cross, extend parallel or be simply in the same vicinity. Cathodic interference is not necessarily a problem, however, merely because two structures are close. Testing must be conducted to determine if remedial measures are required.

Evidence of cathodic interference is usually discovered during routine potential surveys. Abnormal potential readings (in the more positive direction) when observed in the vicinity of a cathodically protected foreign structure are generally a valid indication of interference.

The mechanics of cathodic interference are relatively simple (ref. Figure 2). Cathodic current emanates in all directions from the rectifier and associated anode bed on a given structure. Eventually, the current so discharged will return to the rectifier unit. If a foreign structure lies within the region of current discharge from the rectifier system anodes, it may provide a low resistant path for current return: current collects on the foreign structure (pick-up area), follows the foreign structure to a point where it returns to the given structure (discharge area), flows along the given structure to the negative connection and back to the rectifier, thus completing the circuit. The "pick-up" area is cathodic and hence, no detrimental effects will occur here. The "discharge" area is intensely anodic and severe corrosion damage will take place at this point.

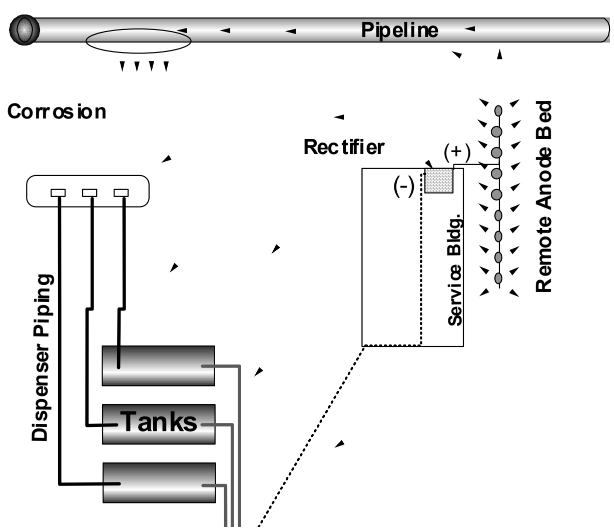


Figure 2 - Remote UST Anode System Causing Stray Current Corrosion on Nearby Pipeline

The solving of interference problems is one of the most complex situations which corrosion engineers encounter. The purpose of the following section therefore, is to outline the fundamentals required to recognize, investigate and alleviate cathodic interference conditions.

Cathodic Interference Testing

When the interference effects are produced by a cathodic protection system, the solutions are reasonably simple (ref. Figure 3) except where complicated by superimposed variable stray currents from the sources such as DC transit systems, welding operations and the like. The following example is offered to clarify the various situations that might arise:

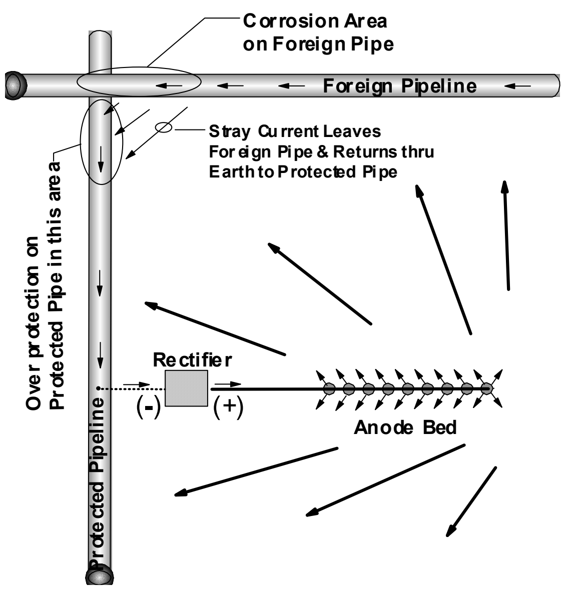


Figure 3 - Cathodic Protection System Induced Stray Current Corrosion

The crossing of a pipeline in the near proximity of the anodes protecting another underground structure (ref. Figure 3).

This example is perhaps the most commonly encountered case of interference. The foreign line collects some of the current from the anode bed associated with another pipeline or storage tanks. This current flows along the foreign line, and then returns to the tank or pipeline through the soil. Damage is inflicted on the foreign line where the current discharges to earth (usually in the immediate vicinity of the crossing).

A bond established between the two structures at the crossing may alleviate the detrimental effects.

If a "solid bond" (ref. Figure 5) is installed, the negligible resistance will allow substantial current drainage from the foreign line to the protected line. This will afford appreciable cathodic protection to the foreign structure, but may drain too much of the current, especially if the foreign structure is bare or poorly coated, in such case, a "resistance bond" should be installed.

This will permit draining just enough current through the bond to prevent inflection of damage to the foreign line and yet maintain protection on the parent line. In considering bonds, the operator of the cathodic protection system must be consulted and in the case of regulated substances, regulations for monitoring of the bonds must be considered.

Basic Solutions for Cathodic Interference

There are three fundamental approaches to the problem of mitigating cathodic interference:

Design: to minimize exposure.

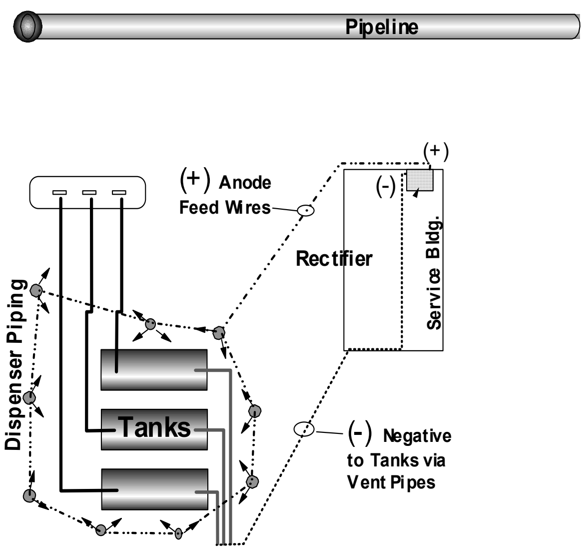
Bonding: to afford a metallic return for current collected by a foreign structure.

Auxiliary Drainage: the use of magnesium anodes to provide auxiliary drainage in the areas of current discharge.

Design: The current density in the earth is far greater in the immediate vicinity of an anode bed than it is elsewhere. Thus, this is the area of most hazardous exposure. Effort should be made to select sites for impressed current systems which are remote from foreign structures. The major design feature which will minimize damage is obviously that of placing the anode bed as far away from foreign structures as possible (ref. Figure 4)

Bonding: Potential reading taken on the foreign line with the reference cell placed directly over the crossing will give an indication as to the interference effects. The ideal situation is to have a bond station near the crossing with a test lead from each pipeline brought into a test box. Interrupt the nearby rectifier and record "on" and "off' readings on each test lead.

Figure 4 - Distributed UST Anode System Designed to Avoid Interference with



If the reading on the foreign test lead is much more positive during the "on" cycle than the "off", and the "on" reading is less negative than 0.85 volts, a resistance bond should be established between the two lines via the respective test leads in the box. The bonding procedure must be accomplished during cooperative tests by the corrosion representatives of each structure involved.

Auxiliary Drainage: In many cases, the point of exposure (current discharge) on the foreign structure is not located at a point of crossing. Often the best solution, in such cases, is to install one or more magnesium or zinc anodes at the point of exposure. This will afford sufficient cathodic protection or auxiliary drainage to the affected area and avert the damage perpetuated by the offending system. The anodes will supply a path to ground for the current collected on the foreign structure. The damage, therefore, is inflicted on the magnesium or zinc anode rather than the structure. This same technique can be used in simple crossing cases as a substitute for a bond. The collected current, instead of flowing back to the protected structure, is discharged to earth by way of the magnesium anodes.

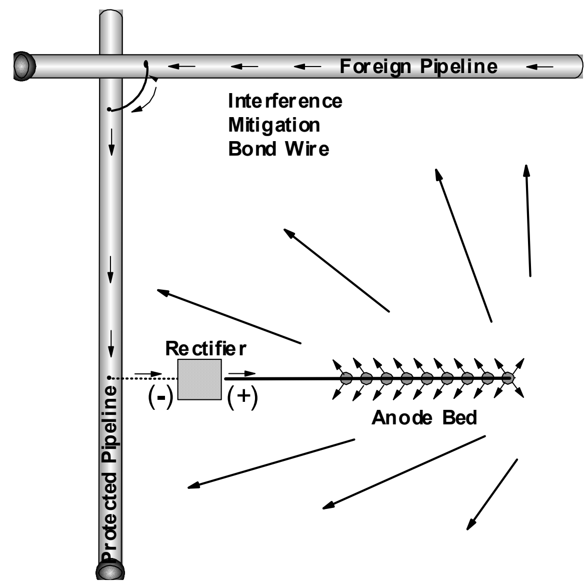


Figure 5 - Stray Current Mitigation using Bond Wire

The number of anodes needed will vary with the amount of current to be discharged. Usually three or five are used in a "string" or "bank" with a single lead provided in a test station for testing and adjustment. The middle anode should be the largest and should be placed at the point of maximum exposure. The placement of the stray current drainage ground bed at the point of discharge on the foreign structure is critical.

Commonly, the center anode is fifty pounds and the others are thirty-two pounds. It is well to choose large anodes because anode life is greatly reduced when used for auxiliary drainage.

Joint Interference Testing

Corrosion engineers are responsible for cooperating with owners of foreign structures in order to coordinate corrosion control measures. Cathodic protection can only be effective if all parties operate their systems with concern for other structures in the area. It has been stated that cooperation is more advantageous than legal pursuits, because the latter do not solve corrosion problems.

The planning of new impressed current cathodic protection systems must include notification to owners of other structures which are near to or cross the subject structure. The owners of foreign structures should be informed of the following:

Location of installation

Type and size of installation

Date of energizing

Locations of known crossings

The owners should be invited to participate in joint interference tests at the crossings and should be asked if other crossings exist not known to the subject company. A written notice should be forwarded and accompanied by pertinent portions of maps marked to show the known foreign crossings and the proposed cathodic protection facilities in the near proximity of those crossings. They should be asked to note any additional structure routes and/or locations on the maps and return them to the subject company.

CRITERIA FOR CATHODIC PROTECTION

General

The purpose of this section is to establish various criteria for cathodic protection. Specific metals will be discussed and potential measurements indicative of cathodic protection presented.

The object of cathodic protection is to control the electrochemical corrosion mechanism of metallic surfaces in contact with electrolytes. No single criteria for evaluating the effectiveness of cathodic protection has proved satisfactory for all conditions. Special cases exist which require alternate interpretation of general criteria. The criteria presented herein has been developed through laboratory analyses and empirical evaluation of successful cathodic protection systems.

In order to establish general criteria for the structures at a project site, it is necessary to consider each specific metal as used in construction of a given facility. In most instances therefore, more than one criterion will be given for a particular metal. Different situations exist which require various means of analysis for each material. For example: steel - coated, bare, tied to copper, tied to zinc, in concrete, etc. each condition necessitates utilizing different criteria for evaluating the level of cathodic protection.

Criteria for Specific Metals

The most generally accepted means of analyzing the effectiveness of cathodic protection employs measurement of structure-to-electrolyte potential with respect to a copper/copper sulfate reference electrode. The following table summarizes typical electrode potentials for the most commonly encountered metals installed underground:

Metal	Potential vs. Cu-$CuSO_4$ Ref. Electrode (Volts)
Commercially pure Magnesium	-1.75
Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	-1.6
Zinc	-1.1
Aluminum alloy (5% zinc)	-1.05
Commercially pure Aluminum	-0.8
Mild Steel (clean and shiny)	-0.7
Mild Steel (rusted)	-0.5

Cast Iron	-0.5
Lead	-0.5
Steel in aerated concrete	-0.2
Mild steel in chloride contaminated concrete	-0.5
Copper, brass, bronze	-0.2

The voltages shown above indicate the potentials normally observed in neutral electrolytes when measured with respect to a copper/copper sulfate reference electrode. These will be helpful in selecting the proper criteria for cathodic protection when more than one metal is involved in an electrically continuous network. Each of the metals discussed will therefore receive multiple consideration with reference to criteria for protection.

Criteria for Carbon Steel, Cast Iron, Black Iron and Stainless Steel

A negative voltage of at least 0.85 volts measured between the structure surface and a saturated copper/copper sulfate reference electrode in contact with the electrolyte.

A minimum negative (cathodic) polarization voltage shift of 100 mV measured between the structure surface and a stable reference electrode contacting the electrolyte (Note: This criteria is not valid for Stainless Steel). This polarization voltage shift is to be 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 shall be used as the base reading from which to measure polarization decay.

Comments

The corrosion engineer shall consider and compensate for voltage (IR) drops other than those across the structure-electrolyte interface for valid interpretation of all potential measurements.

All structure-to-electrolyte potential measurements shall be observed with the reference electrode placed on the electrolyte as close to the structure surface as possible.

Special cases may exist which require the use of alternate criteria for cathodic protection. Measurements of current loss and gain on the structure and current tracing through the electrolyte have been successfully applied in such cases.

Abnormal conditions sometimes exist where cathodic protection is ineffective or only partially effective. Such conditions include elevated temperatures, stray electrical fields, shielding, presence of sulfate reducing bacteria and unusual contaminants in the electrolyte.

Refer to NACE RP0169 for additional information.

TROUBLE SHOOTING PROCEDURES

Impressed Current Cathodic Protection Systems

History

When impressed current systems are operating improperly, several considerations should be explored prior to testing rectifier components and circuits:

Past Data - DC output of rectifier; structure-to-soil potentials; insulation checks

New Construction - Cable breaks and inadvertent shorts to foreign structures

Installation of new foreign cathodic protection systems

Extensive use of DC in area

Recent storms

Equipment

Fluke Model 75 or equal

AC circuit tester (light with test leads)

Pipe and cable locator

Test leads with booted alligator clips

Shunts

Hand tools: screw driver, wrenches, pliers, etc.

Rubber mat

Precautions

Turn the rectifier off before adjusting any components within the unit. Open both the AC and DC circuit breakers.

Refer to the rectifier wiring diagram before starting to trouble shoot.

When inspecting components while the unit is energized, employ great care and stand on a rubber mat.

Make certain that the instruments used for testing are properly connected. A voltmeter must be connected in parallel while an ammeter is connected in series with the circuit to be measured. Millivolt meters shall only be used across the rectifier shunt. De-energize the circuit before using an ohmmeter to avoid damaging the instrument. Correct polarity must always be maintained when using DC instruments.

Minor Problems

Many rectifier problems are obvious to the experienced technician and do not require elaborate inspection procedures. The obvious should never be ignored. The majority of rectifier failures occur from: blown fuses, loose connections, defective meters or open DC cables. These can generally be detected by a simple visual inspection of the unit.

No DC voltage and/or current.

- Blown DC fuse – this fuse fails, a DC voltage will be observed but a zero current output will be read.
- If apparently due to steady overload, reduce the output slightly.
- If the fuse blows repeatedly, even with the output reduced, the short circuit may be caused by a defective component.
- If the fuse blows occasionally for no apparent reason, the cause may be:

Temporary overload due to seasonal changes in anode bed resistance.

Surges of AC voltage.

Intermittent shorts in rectifier components.

Intermittent shorts in ground bed circuit.

Blown AC fuse – If this fuse fails, neither voltage nor current will be observed in the DC circuit. Check the fuse with a light or AC voltmeter. Replace if necessary. Do not overlook the possibility that service to the rectifier may be interrupted.

Loose connections: Check all connections, especially the AC voltage selector (dual input units only), fine and coarse transformer tap adjustments and stack connections.

Defective meters:

DC voltmeter – If a current output is indicated on the DC ammeter, but no voltage is observed, place a portable voltmeter across the DC terminals. If no voltage is indicated on the portable meter, check to be sure the ammeter is not frozen by turning the unit off. If a voltage is recorded, check for an open in the voltmeter circuit. This can usually be done by removing the voltmeter and visually inspecting the circuit. If no defect is observed, replace the voltmeter.

DC ammeter – If a voltage is indicated on the DC voltmeter, but no current is observed, insert an ammeter in the DC circuit. Turn the unit off and disconnect the positive DC cable. Connect the positive terminal of the ammeter to the rectifier lug and the negative terminal to the anode cable. Turn the unit on and observe the meter. If current flow is indicated, check the ammeter circuit for loose or open connections. If no defects are observed, replace the ammeter.

Opens in the ground bed cables – One of the more common problems which develop with impressed current systems, especially in congested areas, is a break in the anode circuit. Detection of an open in either the positive or negative leg is relatively simple. Monthly data on the rectifier current and voltage outputs is used to determine if the cable has slowly deteriorated or if the cables have been severed. In most cases where a faulty DC lead is encountered, the voltage output will be near the level last recorded, but the current output will be very slight, if any. The steps taken to determine which lead (or leads) is open and the method to locate the break are as follows:

Open the negative cable – If the break is suspected in the negative connection, attach a test lead from the structure (clip to a test station, valve box, or any accessible point of contact) to the negative DC terminal of the rectifier. If the negative cable is in fact open, the test lead will complete the circuit and current flow will be observed. Examine the route of the negative cable to determine if any digging has recently occurred in the area.

Open in positive cable - A break in the ground bed circuit most commonly occurs in the positive leg. This is due to the fact that any break in the insulation which exposes bare copper will result in current discharge to ground at that point. A complete severance of the cable will shortly follow. If the open occurs before the first anode, the entire ground bed will be lost. It should be noted, however, that breaks may occur at any point within the circuit. If only a portion of the anode string is disconnected, the anode bed resistance will increase appreciably (i.e. for a given DC voltage, the current will drop). To determine if the positive leg is in fact open, install a temporary anode bed and connect to the positive terminal of the rectifier. If current flows in the temporary circuit, disconnect and use the conductive method with a pipe and cable locator to pinpoint the break. Disconnected anodes can be located by observing structure-to-soil potentials with the reference electrode placed immediately over the anode locations. A peak will be observed over each functional anode; disconnected anodes will give no indication.

Opens in negative and positive cables - Negative and positive cables are frequently installed in the same ditch line and therefore the possibility of opens in both wires should not be overlooked. The same procedures should be employed as described above.

Low Voltage – If the voltage is only about half what it should be (use circuit resistance as calculated from previous rectifier readings) when the current output is at the maximum, the trouble may be due to:

Open circuits in half the stacks resulting in half-wave rather than full-wave rectification – This can be detected by turning the unit off and feeling the individual plates or heat sinks of the stacks. If some of the plates are warm and part are cold, the stacks have an open circuit and are half-waving.

Rectifier connected for higher AC voltage than being supplied.

In a three phase unit, additional problems may arise from an open circuit resulting in lower current in one phase than in the other two. This can be due to uneven aging of stacks or low line voltage.

Major Rectifier Defects

When the rectifier unit is not functioning properly, systematically isolate the components until the defective part is located.

Sacrificial Anode Cathodic Protection Systems

History

Sacrificial anode systems are basically simple and the problems encountered generally involve fundamental principles. The protective current is generated by the difference in natural potential between the anode and the structure. The magnitude of current produced is small and dependent upon the resistivity of the electrolyte. The current generated will remain constant if: the anode structure circuit is not broken; the resistivity of the electrolyte remains constant; and the resistance at the anode/electrolyte and structure/electrolyte interfaces remain the same. For reinforced concrete pipelines, the most common form of sacrificial anode cathodic protection consists of zinc anodes. Steel or iron pipelines are provided with a high quality dielectric coating to assure that only a very small amount of cathodic protection current is required to protect the exposed surfaces at "holidays"or faults in the coating.

The expected life of a sacrificial anode system is dependent upon the amount of current generated. A fairly accurate projection can be made if the anode size, date of installation and resistivity of the environment is known. More accurate predictions can be made if the protected structure's potential is known. The most accurate method for predicting anode life is based on measuring the current output of the anode and calculating the consumption rate based on Faraday' law.

When attempting to solve problems with sacrificial anode systems, it is helpful to review the past performance of the system under consideration. The following is a list of data that should be compiled prior to initiating field procedures:

- Structure data:
- Date Installed
- Type of Coating (if any)
- Total Surface Area and Structure Geometry
- Type of Material (steel, stainless steel, galvanized, aluminum, etc.)
- Connections (welded, threaded couplings, etc.)
- Insulators (nylon bushings, flanges, unions, etc.)
- Location of Foreign Structures within five feet of the protected structures.

Anode Data:

- Date Installed
- Material (magnesium or zinc including alloy type)
- Size and Weight
- Number
- Location
- Method of Connection to Structure (direct weld-on, individual lead attachment or header cable)
- As Built Construction Drawings

Systems Data

Structure-To-Soil Potential

- Unprotected Static (if the potential shift criteria is to be used)
- Protected Polarized
- Upstream and Downstream of Insulators
- Current Output (if system test points are provided for this purpose)
- Soil Resistivity

Original Corrosion Survey

It is advantageous, to compile as much background information as possible in order to determine overall physical changes in galvanic cathodic protection systems.

Equipment

- Fluke Model 75 or equal
- Copper/copper sulfate reference electrode
- Pipe and cable locator
- Resistivity meter
- Insulation checker
- Probe bar
- Assorted test leads and jumper cables
- Hand tools

Procedure

Sacrificial anode cathodic protection systems are basic from the point of view that the driving voltage and the current output change very little. Some of the variables which may decrease the effectiveness of the system are, (1) inadvertent shorts to other structures, (2) opens in the anode-to-structure circuit, (3) changes in anode-to-earth resistance, and (4) deterioration of the coating.

<u>Inadvertent Shorts</u>

Sacrificial anodes generate only small amounts of current and therefore can only be used in proportion to the projected current output. The majority of smaller structures employing sacrificial anode systems in congested areas must be isolated from other underground metallic structures. If the anode is not totally consumed and structure-to-soil potentials reveal inadequate protection, a short to a foreign structure is likely. An isolation check should therefore be performed as follows:

- Check all insulators above grade by using the fixed cell/moving ground technique to measure the potentials on either side. If the potentials are the same, the insulator is probably faulty.
- If in doubt, double check the observed results using the AC impedance measuring technique.
- Check all insulators below grade by one of the methods outlined previously.
- If all insulation installed to isolate the subject structure has been found effective, an inadvertent short may exist either above or below grade. Above ground shorts can usually be detected by visual examination. Locations where recent construction has taken place are the most likely and therefore should be examined first.

<u>Opens in Anode Structure Circuit</u>

A cathodic protection system, be it impressed current or sacrificial anode, must have a complete circuit from the anode to the structure. Damage to the lead wires is one of the common problems to be considered in trouble shooting sacrificial anode systems.

<u>Individual anode connections to the structure</u>

In applications where sacrificial anodes are attached individually by lead wires to the structure, the potential level of the structure may decrease gradually. This normally denotes either deterioration of anode material or system coating, but may be caused by disconnected anodes. Where appropriate test points are available, the current output of the anode may be measured to determine the effectiveness.

Anodes connected to structure by way of <u>collective header</u>

In many cases a collective header cable is utilized. A total failure of the cathodic protection system as revealed by current output or structure-to-soil potential measurements, most commonly results from a break in the anode structure circuit. Recent construction may be the cause, in which case the break area may be quite obvious. If a break is not in evidence and the cable is accessible, use the conductive method with a pipe and cable locator to pinpoint the open.