



**AIR FORCE HANDBOOK 32-1290(I)  
MIL-HDBK-1136/1  
(SUPERSEDES NAVFAC MO-306.1)  
1 February 1999**

**CATHODIC PROTECTION  
FIELD TESTING**



DEPARTMENTS OF THE AIR FORCE AND NAVY

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**BY ORDER OF THE  
SECRETARIES OF THE AIR FORCE  
AND NAVY**

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**Civil Engineering**

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**CATHODIC PROTECTION FIELD TESTING**

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This handbook summarizes actions to be taken in operating and maintaining various cathodic protection systems in use at military installations. Considerable instruction is also provided on conducting the testing procedures necessary for ensuring proper functioning of the systems. It is meant primarily to aid the craftsman at unit level in performing their duties and responsibilities.

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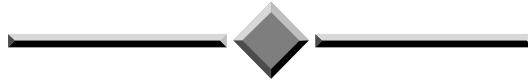
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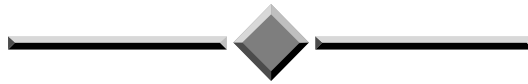
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## CHAPTER 1 OPERATION OF CATHODIC PROTECTION SYSTEMS

1.1. Maintaining Cathodic Protection Systems requires periodic (recurring) maintenance to ensure proper operation. The required surveys and intervals are identified in MIL HDBK 1136, *Operation and Maintenance of Cathodic Protection Systems*.

1.2. The Close Interval Corrosion Survey is conducted to ensure that the entire structure has adequate cathodic protection.

1.2.1. Preferred equipment: Data Logger, Current Interrupters (or Synchronizable Current Interrupters for impressed current systems with multiple rectifiers), low frequency pipe locator (120-cps for impressed current systems), motorized wire wheel or wire dispenser (backpack or hip pack) and data probe with copper/copper sulfate electrode (figure 1.1).

**Figure 1.1. Using Data Logger for Close Interval Survey.**



1.2.1.1. Other equipment which may be used includes waveform analyzers with pulse generators (for impressed current systems with one to 11 rectifiers), or high input resistant DC voltmeter (10 megaohms or higher), wire reels, intermediate electrode extension, and copper/copper sulfate electrode.

1.2.2. Check serviceability of reference electrode (half-cell), meters, meter leads, wire reels, and other equipment.

1.2.3. A systematic approach should be taken to cover the entire structure with high accuracy for recording locations of potential measurements taken (table 1.1).

1.2.4. Take required potential measurements.

1.2.4.1. "On" and "instant off" potential measurements must be taken at intervals not to exceed the depth of the pipeline or structure being tested.

1.2.4.2. Normally, the interval used is kept uniform over the entire structure.

1.2.4.2.1. Take accurate notes to record location information.

1.2.4.2.2. Use pipe locator to ensure measurements are taken directly over pipelines (figure 1.2).

1.2.5. Locations of all physical structures should be noted, especially when potential readings can't be taken due to asphalt or other physical obstructions.

1.2.5.1. Note exact length of the structure where potential measurements were not taken.

1.2.5.2. Locations to be noted may include roads, sidewalks, railroads, valves, pits, buildings, ditches, retaining walls, foreign pipeline crossings,



test stations, fences, parking lots, waterways, or other significant location, such as where the structure comes out of the ground for any reason.

**Table 1.1. Close Interval Survey Potential Measurement Requirements.**

<b>STRUCTURE TYPE</b>	<b>POTENTIAL MEASUREMENT LOCATIONS</b>
<b>PIPELINES</b>	At intervals not to exceed the depth of the pipeline, normally every 3 to 5 feet
<b>ON GRADE STORAGE TANKS</b>	Next to the tank every six feet around the tank circumference.
	At a distance one tank radius away from the tank, at eight equally spaced locations around the tank circumference
<b>UNDERGROUND STORAGE TANKS</b>	With the reference cell located: Every three feet over the tank
	At least every three feet over feed and return piping.
	Over the manhole, fill pipe, and vent pipe
	Over all metallic structures in the area if readings indicate an isolated system is shorted to a foreign structure.
<b>ISOLATED STRUCTURES</b>	One measurement on each side of all dielectric couplings.
<b>ALL STRUCTURES WITH FOREIGN LINE CROSSINGS</b>	Connect structure lead to foreign pipeline: Over the foreign line at all points where it crosses the protected structure.
	Over the foreign line where it passes near by the anode bed
<b>ALL STRUCTURES WITH CASED CROSSINGS</b>	Over each end of the casing on all casings.
<b>ALL STRUCTURES IN SOIL</b>	Annotate the soil condition.

**Figure 1.2. Using Pipe Locator to Make Measurements Directly Over Pipeline.**



1.2.6. Note location of structure connection for all potential measurements.

1.2.6.1. When the structure connection location is changed, it must be recorded in the data, and a portion of previous readings should be duplicated to ensure consistency of data (and continuity of the structure).

1.2.6.2. If instant off potential measurements are exactly the same after moving the structure connection, this may not be required.

1.2.6.3. If instant off potential measurements change significantly when moving the structure connection, more potentials may need to be taken.

1.2.6.4. This condition should be noted in the data, so that the location can be re-visited for future testing and troubleshooting.

1.2.7. Potentials should also be taken on foreign metallic structures, which cross or are located near the protected structure, especially when a gradient is observed on the protected structure.

1.2.8. Data should be entered into a computer database and checked for erroneous readings.

1.2.8.1. Erroneous readings can result from not making good contact to earth with the reference cell, lifting the reference cell too early or by pressing the trigger too early.

1.2.8.2. All data should be reviewed for errors when entered into the database.

1.2.9. Graphing Data: After verification of the data, the data should be graphed by data base software or by copying the data into a spreadsheet application. This graphical presentation of the data allows for easy analysis.

1.2.10. Analyzing Data: Presenting the data graphically allows overlay of criteria lines or curves, which easily identifies areas which do not meet the criteria for protection.

1.2.10.1. Other anomalies in the data are also easily recognized.

1.2.10.2. Trends, which may not have been apparent when looking at the potential measurements, will be readily seen on the graphs.

1.2.10.3. Looking at the graph of the data may uncover areas of the structure where further testing or troubleshooting is required.

1.2.10.4. The data may also be overlaid with previous survey data or future survey data to allow easy recognition of changes or other anomalies.

1.2.11. Other tests required include anode and rectifier checks shown in table 1.2 (these requirements are detailed in MIL HDBK 1136).

**Table 1.2. Close Interval Survey Component Test Requirements.**

CP SYSTEM TYPE	TEST MEASUREMENT
<b>GALVANIC SYSTEMS</b>	Anode-to-soil potential measurement Anode-to-structure current
<b>IMPRESSED CURRENT SYSTEMS</b>	Rectifier operational checkout Rectifier efficiency Impressed current anode bed survey

1.3. The Corrosion Survey is conducted to reasonably ensure that the entire structure still has adequate cathodic protection.

1.3.1. Preferred Equipment: Data Logger, Current Interrupters (or Synchronizable Current Interrupters for impressed current systems with multiple rectifiers), motorized wire wheel or wire dispenser (backpack or hip pack) and data probe with copper/copper sulfate electrode (figure 1.3). Other equipment which may be used includes waveform analyzers with pulse generators (for impressed current systems with one to 11 rectifiers), or high input resistant DC voltmeter (10 megaohms or higher), wire reels, intermediate electrode extension, and copper/ copper sulfate electrode.

**Figure 1.3. Synchronizing Current Interrupters.**

1.3.2. Check serviceability of reference electrode (half-cell), meters, meter leads, wire reels, and other equipment.

1.3.3. Take required potential measurements.

1.3.3.1. Data from the close interval corrosion survey should be analyzed to determine the best locations for data collection during the corrosion survey.

1.3.3.2. This is normally the low and/or the high potential locations, according to the trends in that data.

1.3.3.3. If a close interval survey has never been done, it would be wise to perform the close interval survey in lieu of the corrosion survey.

1.3.3.4. "On" and "instant off" potential measurements must be taken. If data from a close interval corrosion survey is not available, sufficient test locations should be selected to ensure that the entire structure is protected.

1.3.3.5. See table 1.3 for general recommendations of potential locations.

1.3.4. Take accurate notes to record location information.

1.3.5. Examine all data collected to ensure erroneous potential measurements are not included in the database.

1.3.6. Compare measurements to previously recorded data.

1.3.7. Other tests required include anode and rectifier checks shown in table 1.4. These requirements are detailed in MIL HDBK 1136.

**Table 1.3. Corrosion Survey Potential Measurement Requirements.**

STRUCTURE TYPE	POTENTIAL MEASUREMENT LOCATIONS
<b>PIPELINES</b>	Over the pipeline at all test stations and at all points where the structure can be contacted Over the pipeline at least every 1000 feet for pipelines off the installation Over the pipeline at least every 500 feet for pipelines on the installation
<b>ON GRADE STORAGE TANKS</b>	With the reference cell located: Next to the tank at four equally spaced locations around the tank circumference At a distance one tank radius away from the tank at eight equally spaced locations around the tank circumference
<b>UNDERGROUND STORAGE TANKS</b>	With the reference cell located: Over the center and each end of the tank Over each end of the feed and return piping Over the manhole, fill pipe, and vent pipe Over all metallic structures in the area if readings indicate an isolated system is shorted to a foreign structure.
<b>ISOLATED STRUCTURES</b>	One structure-to-electrolyte (S/E) potential measurement on each side of all dielectric couplings without moving the reference electrode <b>Note:</b> If the potential difference between measurements on each side of a dielectric coupling is less than 10 millivolts, verify its integrity using an isolation flange tester

**Table 1.4. Corrosion Survey Component Test Requirements.**

<b>CP SYSTEM TYPE</b>	<b>TEST MEASUREMENT</b>
<b>GALVANIC SYSTEMS</b>	Anode-to-soil potential measurement Anode-to-structure current
<b>IMPRESSED CURRENT SYSTEMS</b>	Rectifier operational checkout Rectifier efficiency Impressed current anode bed survey

1.4. The Water Tank Calibration is conducted to ensure that the entire structure has adequate cathodic protection, without the presence of over voltage, which may damage the coating.

1.4.1. Preferred Equipment: Radios, Data Logger, Current Interrupter, wire reel, voice activated headsets, inflatable raft, oar, magnetized handle, rope, submersible adapter, and copper/copper sulfate electrode. Other equipment which may be used includes waveform analyzer with pulse generator, or high input resistant DC voltmeter (10 megaohms or higher).

1.4.2. Check serviceability of reference electrode, meters, meter leads, wire reels, and other equipment.

1.4.2.1. Ensure that reference electrode connection is made with a submersible adapter, or that it is a water tank reference electrode.

1.4.2.2. Exposure of the copper connection to the water will result in erroneous measurements.

1.4.3. Take required potential measurements.

1.4.3.1. "On" and "instant off" potential measurements should be taken of the tank wall, at the surface, midway down the tank, and at the bottom, adjacent to and between all anode strings.

1.4.3.2. The tank bottom should have potential measurements taken directly below tank wall anode strings, stub anode strings, and between the anode strings.

1.4.3.3. For elevated towers with "wet" risers, close interval measurements should be taken near the riser wall for the entire length of the riser (normally every 2 to 5 feet).

1.4.4. Take accurate notes to record location information.

1.5. The rectifier operational checkout is used to ascertain the serviceability of all the components necessary to impress current to the anodes of the impressed current system.

1.5.1. It should be a thorough checkout to ensure dependable current until the next inspection.

1.5.2. This checkout should be accomplished in conjunction with the close interval corrosion survey, the corrosion survey, the water tank calibration, or when any inspection or survey indicates that problems with the rectifier may exist.

1.5.3. Preferred Equipment: Handheld multimeter with AC, DC, ohms, and diode circuits and suitable test leads.

1.5.4. The rectifier operational checkout should include the following: Visual check of all rectifier components, shunt box components, safety switches, circuit breakers and other system power components.

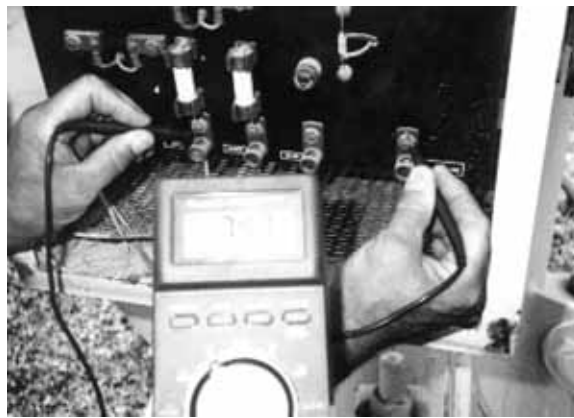
1.5.4.1. Tightening of all accessible connections and temperature check of all components.

1.5.4.2. Check serviceability of meters, meter leads, and other equipment.



1.5.4.3. Measure the output voltage and current and calibrate the rectifier meters, if present (figures 1.4 and 1.5).

**Figure 1.4. Measuring Rectifier Output Voltage.**



**Figure 1.5. Measuring Rectifier Output Current.**



1.5.4.4. For rectifiers with more than one circuit, measure the output voltage and current for additional circuit(s), and calibrate other rectifier meters, if present.

1.5.4.5. For rectifiers with potential voltmeters, measure and calibrate each meter. Using a known good reference electrode, measure the potential difference to the installed permanent reference electrode.

1.5.5. Calculate the cathodic protection system circuit resistance of each circuit, by dividing the rectifier DC voltage output of each circuit by the rectifier DC ampere output for that circuit.

1.5.6. For all Close Interval Corrosion Surveys or if otherwise required, calculate the rectifier efficiency.

1.6. The impressed current anode bed survey is a non-interrupted survey of the ground bed to determine the condition of the anodes and is performed to ensure that all anodes are fully operational.

1.6.1. Preferred Equipment: Data Logger, motorized wire reel, and data probe with copper/copper sulfate electrode. Other equipment which may be used includes high input resistant DC voltmeter (10 megaohms or higher), wire reels, intermediate electrode extension, and copper/copper sulfate electrode.

1.6.1.1. Check serviceability of reference electrode (half-cell), meters, meter leads, wire reels, and other equipment.

1.6.1.2. As a minimum an impressed current anode bed survey should include potential measurements over the anodes at intervals described in table 1.5

**Table 1.5. Recommended Over the Anode Intervals For The Impressed Current Anode Bed Survey.**

CP SYSTEM TYPE	TEST MEASUREMENT
<b>REMOTE SHALLOW ANODE GROUND BEDS</b>	Connect structure lead to negative terminal of rectifier. Anode-to-soil potentials taken at 2 foot intervals along the length of the anode bed, beginning 10 feet before the first anode, and ending 10 feet past the last anode in the ground bed Plot test results on graph paper to give a visual indication of the anode bed condition
<b>DISTRIBUTED SHALLOW ANODE GROUND BEDS</b>	One anode-to-soil potential with the reference cell located directly over each anode One anode-to-soil potential with the reference cell located 10 feet on two opposite sides of the anode
<b>DEEP ANODE GROUNDBEDS</b>	In lieu of anode potential measurements, measure anode circuit current Measure the anode current for each anode if separate leads are available

1.7. The impressed current system check is performed to ensure that the system is operating at the same level as the last survey and to reasonably ensure that the current output of the system is still sufficient.

1.7.1. Preferred Equipment: High input resistant DC voltmeter (10 megaohms or higher), wire reel, and a copper/copper sulfate electrode. Other equipment that may be used includes Data Loggers with data probes, waveform analyzers, or handheld multimeter with AC, DC, ohms and diode check circuits.

1.7.2. The following are the recommended minimum requirements for conducting an impressed current system check.

1.7.2.1. Check serviceability of meters, meter leads, and other equipment.

1.7.2.2. Measure rectifier DC voltage and DC ampere outputs.

1.7.2.3. Calculate the rectifier system circuit resistance by dividing the rectifier DC output voltage by the rectifier DC output current. If the rectifier has more than one circuit, calculate the resistance of each circuit.

1.7.2.4. Take potential measurements at the locations of the three lowest and the highest potential measurements identified in the most recent close interval or corrosion survey.

1.7.2.5. Compare the potential measurements and the DC ampere output of the rectifier to the last close interval or corrosion survey.

1.7.2.5.1. If potential measurements do not meet criteria, and the rectifier current output does not meet the current requirement from the last survey, adjust the CP system to that level and repeat testing.

1.7.2.5.2. If potential measurements do not meet the criteria, and the rectifier current output meets the current requirement from the last survey, adjust or supplement the CP system as necessary and repeat testing. Conduct a corrosion survey 30 days after adjustment or modification to the cathodic protection system to establish the new current requirement.

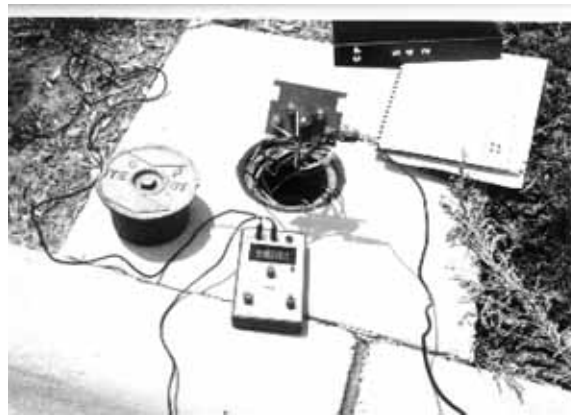
1.8. The galvanic anode check is conducted to determine its operational condition. The checkout is normally conducted as part of the close interval or corrosion survey.

1.8.1. Preferred Equipment: High input resistant DC voltmeter (10 megaohms or higher), wire reel, and a copper/copper sulfate electrode. Other equipment that may be used includes data loggers with data probes, waveform analyzers, or handheld multimeter (10 megaohms or higher input resistance).

1.8.2. Check serviceability of meters, meter leads, and other equipment.

1.8.3. Disconnect anode and measure potential with reference cell over the anode (figure 1.6).

**Figure 1.6. Measuring Potential of Galvanic Anode.**



1.8.4. Measure anode output current (figure 1.7).

1.8.5. Compare to previous measurements for any changes.

1.9. The resistance bond check is an operational check of two metallic structures connected with some type of semi-conductor or resistor, to ensure that the structures affected by the bond are maintained at proper potentials.

1.9.1. Preferred Equipment: Handheld Multimeter with AC, DC, ohms and diode check circuits, wire reel, and a copper/copper sulfate electrode. Other equipment that may be used includes Data Loggers with data probes, waveform analyzers, or high input resistant DC voltmeter (10 megaohms or higher).

**Figure 1.7. Measuring Output Current of Galvanic Anode.**



1.9.2. The following are the recommended requirements:

1.9.2.1. Check serviceability of meters, meter leads, and other equipment.

1.9.2.2. Note rectifier(s) DC voltage and ampere output if structure is protected.

1.9.2.3. Measure the DC ampere current flow and direction.

1.9.2.4. Take potential measurements on both sides of the bond.

1.9.2.5. Compare to previous measurements to determine if changes have occurred.

1.9.3. If the potential measurements, current flow, current direction or other measurement has changed from the last check, adjust or repair the component as necessary, and repeat the test of the bond.

1.10. The leak survey is performed to determine the cause of the leak and to determine the corrective action required in preventing future leaks.

1.10.1. Preferred Equipment: High input resistant DC voltmeter (10 megaohms or higher), wire reel, antimony half-cell and a copper/copper sulfate electrode. Other equipment that may be used includes data loggers with data probes, waveform analyzers, or handheld multimeter (10 megaohms or higher input resistance).

1.10.2. Check serviceability of meters, meter leads, and other equipment.

1.10.3. Measure the potential with the reference electrode near the surface of the structure.

1.10.4. Measure the pH of the electrolyte near the surface of the structure.

1.10.5. Perform a visual inspection of the structure coating and note its condition.

1.10.6. Inspect the structure surface at and around the point of the leak.

1.10.6.1. Determine corrosion caused or contributed to the failure.

1.10.6.2. If corrosion caused the failure, examine corrosion to determine the type of corrosion (see MIL HDBK 1136, chapter 2 for types of corrosion) which caused the failure (galvanic, interference, oxygen concentration, etc.).

1.10.7. If structure is under cathodic protection, conduct a checkout of that system and perform a corrosion survey of the structure affected by that system.

1.10.8. Determine the corrective action required in preventing future leaks on the structure.

1.11. Records must be kept on file for all structures with cathodic protection systems.

1.11.1. All surveys included in this section should be filed in a folder for that specific cathodic protection system.

1.11.2. All these records are instrumental for future operations, maintenance and testing of cathodic protection systems and protected structures.

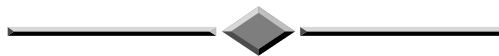
1.11.3. Historical data expedites troubleshooting of cathodic protection systems, should that requirement become necessary.

1.11.4. Historical data is necessary to maintain the infrastructure at its lowest life cycle cost.

1.11.5. This data is instrumental in planning and installing new or replacement structures.

1.11.6. Military policy, regulations, instructions and other requirements mandate these records to be maintained.

1.11.7. In some cases public law requires these records to be maintained for specific intervals.





## **CHAPTER 2 MAINTENANCE OF CP SYSTEMS**

2.1. CP Systems require unscheduled maintenance to repair systems when they are not operating properly.

2.1.1. Detailed procedures can be found in MIL HDBK 1136, Chapter 5, Unscheduled Maintenance Requirements.

2.1.2. If adequate CP does not exist on the protected structure, then troubleshooting must be accomplished to determine the cause of this lack of protective current. The first step in troubleshooting is to determine which component is faulty.

2.1.3. Isolation of problems on Impressed Current CP Systems is accomplished by testing performed at the power source, normally the rectifier (and the dielectrics on isolated systems).

2.1.4. In galvanic systems, troubleshooting from the test stations (and dielectrics on isolated systems) will identify the component that has failed.

2.1.5. Impressed current systems have a large number of components that may fail.

2.1.6. Galvanic systems are normally trouble free, until anode life has been reached.

2.2. Troubleshooting Impressed Current CP Systems begins at the power source, normally a rectifier. For automatic rectifiers, see paragraph 2.2.20.

2.2.1. Visually check rectifier for abnormal conditions.

2.2.2. Measure the DC voltage output (Negative to Positive terminals).

2.2.3. Measure the DC current output of the rectifier using one of the following methods (in order of accuracy):

2.2.3.1. Using a clamp-on direct current milliammeter.

2.2.3.2. Measuring MV drop across a calibrated shunt with multimeter set on mV and multiplying by the proper multiplier (see table 2.1).

**Table 2.1. Shunt Multiplication Factors.**

Shunt size	Multiplier	Shunt size	Multiplier
50 mV / 5 Amp	.1	50 mV / 45 Amp	0.9
50 mV / 10 Amp	.2	50 mV / 50 Amp	1
50 mV / 15 Amp	.3	50 mV / 55 Amp	1.1
50 mV / 20 Amp	.4	50 mV / 60 Amp	1.2
50 mV / 25 Amp	.5	50 mV / 65 Amp	1.3
50 mV / 30 Amp	.6	50 mV / 70 Amp	1.4
50 mV / 35 Amp	.7	50 mV / 75 Amp	1.5
50 mV / 40 Amp	.8	50 mV / 100 Amp	2

2.2.4. Disconnect positive (anode) lead and using an ammeter in series.

2.2.5. Compare those measurements to previous readings taken during normal operation.

2.2.6. Categorize the readings as high, normal, half of normal, low, or at or near zero.

2.2.7. Use table 2.2 to determine possible problems and take the actions required to isolate the problem.

2.2.8. Loss of structure isolation is the most common reason of low potentials with normal or high rectifier output.

2.2.8.1. Check potentials on both sides of dielectrics. Higher than normal potentials on the house side of the dielectrics indicate a short somewhere in the system.

**Table 2.2. Troubleshooting Impressed Current CP Systems.**

<b>Condition</b>		<b>Possible Problems</b>	<b>See Para. No.</b>
<b>Voltage</b>	<b>Current</b>		
Normal	Normal (or high)	Loss of structure isolation Change in amount of structure protected Failure of structure coating Error of installed meters	2.2.8 2.2.9 2.2.10 2.2.11
Normal	Low	Rise in circuit resistance (drying of anodes) Failed header cable between anodes or deterioration of one or more anodes Polarization of anode bed	2.2.12 2.2.13 2.2.13
Normal	At or near Zero	Failed header cable Loss or deterioration of anodes Loss of electrolyte (no water in water tanks) Failure of structure lead	2.2.14 2.2.13 2.2.15 2.2.16
Half of Normal	Half of Normal	Loss of rectifier diode Loss of connection in rectifier diode circuit Low AC input	2.2.16 2.2.16 2.2.17
At or near Zero	At or near Zero	Loss of rectifier AC input Blown fuse or tripped circuit breakers Loss of connection in rectifier Rectifier transformer failure Failure of rectifier stacks	2.2.16 2.2.16 2.2.16 2.2.16 2.2.17
Fuse blows or Circuit Breaker trips when unit is energized		Loss of structure isolation Short in rectifier wiring or lightning Arrestor Anode lead shorted to structure, negative terminal, or grounded rectifier case Anodes touching structure Improper size fuse installed	2.2.8 2.2.18 2.2.18 2.2.18 2.2.18
Excessive heat produced in rectifier		Stacks deteriorated Resistance in connection Air flow in cabinet restricted Excessive coating on cabinet	2.2.17 2.2.17 2.2.19 2.2.19

2.2.8.1.1. Check all installed dielectrics.

2.2.8.1.2. If all dielectrics check good, look for new services, shorts around dielectrics, current pickup on foreign structures, and/or underground shorts by conducting over-the-line survey using Audio Frequency (or 120-Cps) pipe locator or cell-to-cell procedures.

2.2.8.1.3. Low potentials on house side of the dielectrics indicates other problems.

2.2.9. For systems that are not isolated, the most common reason of low potentials with normal rectifier output, is a change in the amount of structure protected. This may also occur on isolated structures.

2.2.9.1. Check for changes to the structure (additions or changes to the utility system).

2.2.9.2. Check for new projects which may affect the structure (other new utilities which may be shorted to the structure).

2.2.9.3. Visually check right-of-way for new construction.

2.2.10. Failure of structure coating will cause current requirements to go up.

2.2.10.1. Check for construction near structure that may have damaged coating.

2.2.10.2. Raise output and verify proper potentials.

2.2.11. Error of installed meters may indicate low output, even though output is normal.

2.2.11.1. Adjust installed meters to proper reading.

2.2.11.2. Replace defective meters.

2.2.12. Drying of anodes raises circuit resistance, and lowers current.

2.2.12.1. Compare soil conditions to those during previous readings.

2.2.12.1.1. If potentials do not meet criteria because the soil around the anodes has dried out, do not adjust rectifier.

2.2.12.1.2. Anodes are normally deeper than the structure. If anodes are dried out, then the structure is also dried out, lowering the corrosion rate.

2.2.12.1.3. Subsequent wetting of soil could damage system or cause excessive output.

2.2.12.1.4. If potentials still meet criteria, annotate reading, do not adjust rectifier.

2.2.13. Before a great deal of time is expended troubleshooting an anode bed, it should be determined from records if there is sufficient anode material to attempt locating and repairing the fault.

2.2.13.1. If a gradual failure occurred, deterioration of one or more anodes can be expected. If the failure was sudden, a cable break or loss of one or more anodes can be expected. If no anodes are operating, see paragraph 2.2.14.

2.2.13.2. If system permits, measure current output of individual anodes.

2.2.13.3. Perform an anode bed plot.

2.2.13.3.1. Connect positive meter lead to rectifier negative.

2.2.13.3.2. Connect negative meter lead to reference cell.

2.2.13.3.3. Perform a close interval survey over entire length of anode bed (1 or 2 ft intervals).

2.2.13.3.4. Graph results to visualize gradients.

2.2.13.3.5. Examine gradients to identify specific problem(s).

2.2.13.4. If a failed anode is indicated, replace the anode.

2.2.13.5. If a broken anode lead is indicated:

2.2.13.5.1. Look for any excavations which have occurred in the area of the anode cable.

2.2.13.5.2. Use audio frequency pipe locator or fault detector to locate break in cable.

2.2.13.5.3. Repair the cable.

2.2.14. If no anodes are operational:

2.2.14.1. Use the fault detector and cable locator.

2.2.14.1.1. Connected signal generator directly to the anode cable at the rectifier.

2.2.14.1.2. Use a low resistance, isolated ground for signal generator.

2.2.14.1.3. Trace the anode lead from the rectifier towards the anode bed. Repair break.

2.2.14.2. An alternative method is to locate the first anode (from drawings, markers, or induction methods) (figure 2.1).

2.2.14.2.1. Excavate to the first anode.

2.2.14.2.2. Measure continuity back to the rectifier using a Multi-Combination meter continuity check circuit.

2.2.14.2.3. Connect signal generator directly to the anode cable at the anode.

2.2.14.2.4. Use a low resistance, isolated ground for the signal generator.

2.2.14.2.5. Use the fault detector and cable locator to trace the anode lead from the anode towards the rectifier.

2.2.14.2.6. If this is still unsuccessful, replace the anode lead from the rectifier to the first anode.

**Figure 2.1. Using Induction Method to Locate Anodes.**



2.2.15. For anodes in water tanks, if the water level goes down, anodes will no longer be in contact with the electrolyte. If the water level is below all anodes, no current will flow.

2.2.15.1. Check water level gauge.

2.2.15.2. Visually check water level of tank if doubt still exists.

2.2.16. Loss of rectifier AC input is a common problem with impressed current systems.

2.2.16.1. Check for AC voltage at rectifier taps (figure 2.2). If AC is present go to paragraph 2.2.17.

2.2.16.2. Check for tripped circuit breaker. Check AC fuse(s).

2.2.16.3. Pull fuse from holder and use ohmmeter to verify continuity.

**Figure 2.2. Measuring AC Voltage at Rectifier Taps.**



2.2.16.4. Check DC Fuse(s). Pull fuse from holder and use ohmmeter to verify continuity (figure 2.3)

2.2.16.5. Check AC voltage to both sides of circuit breaker with breaker on.

2.2.16.6. Check disconnect, power panel or other power source.



**Figure 2.3. Verifying Continuity of Fuse.**



2.2.17. Testing the rectifier stacks:

2.2.17.1. Check all connections.

2.2.17.2. Disconnect AC input to the rectifier stacks (remove tap bars).

2.2.17.3. Disconnect anode and structure leads.

2.2.17.4. Perform diode check (figure 2.4)

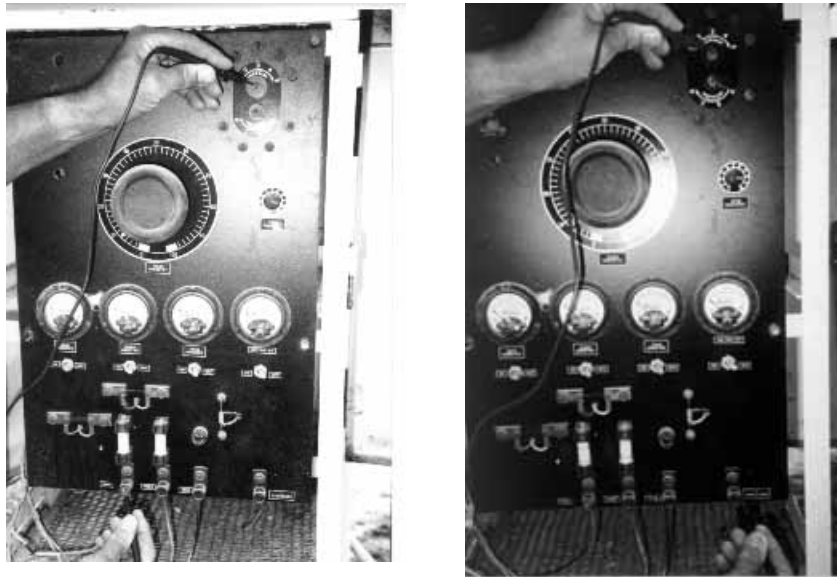
2.2.17.4.1. Use multimeter diode check circuit.

2.2.17.4.2. Measure from rectifier negative to both center taps.

2.2.17.4.3. Reverse leads and repeat.

2.2.17.4.4. Measure from rectifier positive to both center taps.

**Figure 2.4. Performing Diode Check on Rectifier.**



2.2.17.4.5. Reverse leads and repeat.

2.2.17.5. Replace defective diodes, or entire set of stacks.

2.2.18. Fuse blows or circuit breaker trips when rectifier is energized.

2.2.18.1. Check Lightning Arrestor.

2.2.18.1.1. Disconnect from circuit.

2.2.18.1.2. Use ohmmeter to check continuity.

2.2.18.1.3. If continuity exists, replace arrestor.

2.2.18.2. Check anode leads.

2.2.18.2.1. Check continuity of anode lead to structure, negative terminal and grounded rectifier case.

2.2.18.2.2. If continuity is found, visually check wiring. Disconnect any connections, and retest to narrow search.

2.2.18.3. Check if anodes are contacting the structure. Visually check anodes in water tanks to see if they are contacting structure.

2.2.18.4. Improper size fuse installed.

2.2.18.4.1. Determine proper size of fuse by one of the following: Check rectifier rated output., review records or calculate current.

2.2.18.4.2. Install proper size fuse. If proper size fuse still fails, repeat tests in paragraph 2.2.18.

2.2.19. Perform a visual check of the rectifier cabinet.

2.2.19.1. Air flow in cabinet may be restricted by dirt, nests, other foreign materials.

2.2.19.2. Excessive coating on cabinet can reduce heat transfer, especially in very hot environments.

2.2.19.3. Excessive heat in rectifier may damage rectifier components, especially semi-conductors (such as stack diodes or circuitry in automatic rectifiers).

2.2.20. Special Considerations for Automatic Rectifiers.

2.2.20.1. Switch rectifier to manual operation.

2.2.20.2. Check accuracy of permanent reference electrode with known good reference electrode.

2.2.20.3. If proper output is not restored, troubleshoot as per table 2.2.

2.2.20.4. Automatic rectifiers can adjust current only to the maximum setting of the manual taps. If current is too low, tap settings may have to be adjusted.

2.2.20.5. If proper output is restored:

2.2.20.5.1. And automatic operation is not required (fire protection tank or tank where there is only minor water level fluctuation) continue operation in manual mode.

2.2.20.5.2. And automatic operation is required (water tank where the water level constantly changes), troubleshoot automatic circuit. If automatic circuit is on a removable card, replace card with troubleshooting card (if supplied) or replacement card (spare, if available) and retest. See rectifier operating manual for troubleshooting procedures.

### **2.3. Impressed Current System Common Problems.**

2.3.1. Anode lead failure, see paragraph 2.2.13.

2.3.2. Loss of AC power, see paragraph 2.2.16.

2.3.3. Blown fuse or tripped circuit breaker, see paragraph 2.2.16.

2.3.4. Rectifier stack failure, see paragraph 2.2.17.

2.3.5. Loss of structure isolation, see paragraph 2.2.8.

2.3.6. Failure of automatic rectifier operation, see paragraph 2.2.20.

**2.4. Troubleshooting Galvanic (Sacrificial) CP Systems.** The most common problem encountered in galvanic anode systems is the loss of structure isolation.

2.4.1. Check potentials on both sides of dielectrics.

2.4.1.2. Higher than normal potentials on the house (unprotected) side of the dielectrics indicate a short somewhere in the system.

2.4.1.2.1. Check all installed dielectrics using a suitable isolation tester (such as the gas electronics model 601) (figure 2.5).

2.4.1.2.2. If all dielectrics check good, look for new services, shorts around dielectrics, current pickup on foreign structures, and/or underground shorts by conducting over-the-line survey using 120-cps pipe locator or cell-to-cell procedures.

**Figure 2.5. Checking Potentials on Installed Dielectrics.**



2.4.1.2.3. Low potentials on the house side of all dielectrics is normal and indicates good isolation. Other problems are causing the loss of protection.

2.4.2. Before a great deal of time is expended troubleshooting galvanic anode systems, it should be determined from records if there is sufficient anode material to attempt locating and repairing the fault(s).

2.4.2.1. When galvanic anodes begin to fail due to normal consumption, replacement of the CP system should be programmed.

2.4.2.2. Usually, the most cost-effective method of replacing an entire galvanic anode system is by installation of an impressed current system.

2.4.3. If a gradual failure occurred, deterioration of one or more anodes can be expected.

2.4.4. If the failure was sudden, a cable break can be expected. This is most common when anodes are installed on a continuous header cable, and connected to the structure at a test station.

2.4.4.1. Perform an anode bed survey.

2.4.4.1.1. Connect negative meter lead to reference cell.

2.4.4.1.2. Disconnect anode. Connect positive meter lead to the anode lead. Measure potential with reference cell over the anode. Measure anode output current.

2.4.4.1.3. If anode cannot be disconnected, connect positive meter lead to the structure. Measure potential with reference cell over the anode. Measure potential with reference cell over the structure, adjacent to anode and midway between anodes.

2.4.4.1.4. Compare to previous readings for any changes.

2.4.5. If a cable break is indicated.

2.4.5.1. Look for any excavations which have occurred in the area of the anode cable.

2.4.5.2. Use an Audio Frequency pipe locator or fault detector.

2.4.5.2.1. Install transmitter by the direct connection method.

2.4.5.2.2. Ensure a remote low resistance ground for the transmitter.

2.4.5.2.3. Locate the cable break.

2.4.5.3. Repair the cable.

2.4.6. If a failed anode is indicated, replace the anode, unless general failure of all anodes can be expected (see above).



## CHAPTER 3 CP TEST PROCEDURES

**3.1. CP Test Procedures.** Potential measurement is the fundamental test procedure used in CP testing.

### **3.2. Potential Measurement.**

3.2.1. The theory is to measure an unknown potential by relating it to a known reference electrode.

3.2.1.1. In soil and fresh water conditions the copper/copper sulfate reference electrode should be used.

3.2.1.2. In salt water conditions the silver/silver chloride reference electrode must be used.

3.2.2. A high input impedance voltmeter must be used to prevent erroneous readings.

3.2.2.1. The voltmeter must have a minimum of 10 megohms input resistance under normal conditions.

3.2.2.2. Under rocky or very dry conditions the voltmeter should have up to 200 million ohms input resistance.

3.2.3. Meter connection.

3.2.3.1. Digital Meters (figure 3.1).

3.2.3.1.1. Connect negative lead to reference electrode.

3.2.3.1.2. Connect positive lead to structure. Do not use a current carrying conductor for meter connection.



3.2.3.2. Voltmeter which has a D'Arsonval movement needle and has a polarity switch (such as the M.C. Miller Model B3 Series).

3.2.3.2.1. Select (-) on polarity switch.

3.2.3.2.2. Connect negative lead to reference electrode.

3.2.3.2.3. Connect positive lead to structure. Do not use a current carrying conductor for meter connection.

**Figure 3.1. Taking a Potential Measurement with a High Input Impedance Digital Voltmeter.**



3.2.3.3. Voltmeter which has a D'Arsonval movement (needle) which only deflects in the positive direction.

3.2.3.3.1. Connect negative lead to structure.

3.2.3.3.2. Connect positive lead to reference electrode. Do not use a current carrying conductor for meter connection.

3.2.3.3.3. Note that connections must be made backwards to prevent damage to the meter. Interpret the positive deflection as a negative reading.

3.2.4. Five sources of error.

3.2.4.1. The accuracy of the reference electrode used can be a source of erroneous readings.

3.2.4.1.1. Check the accuracy of the reference electrode (half-cell) used to take potential measurements. To determine the accuracy of a reference electrode multiple reference electrodes must be used. Use one reference electrode, which is not used in the field, to check against other reference electrodes.

3.2.4.1.2. A valid reference electrode must be used to take all potential measurements. Temperature also effects the potential of the reference cell. Direct sunlight also effects the potential of the reference cell.

3.2.4.1.3. For the full procedures on initiation of a reference electrode, cleaning of the electrode, preparing the electrolyte solution, and testing of the reference electrode, see MIL HDBK 1136.

3.2.4.2. IR is error present when current is flowing. Recognize that all "ON" readings contain this error.

3.2.4.3. Anode gradient field is present when current is flowing. Recognize that all "ON" readings taken in the gradient field of an anode, contain this error.

3.2.4.4. Contact resistance error. When the reference electrode is not in good contact with the electrolyte this error will result in a low reading. Use water to lower contact resistance (figure 3.2) or select higher input impedance. If reading changes, select even higher input impedance. Continue until no

change in reading occurs. Use formula to calculate approximate reading if required.

**Figure 3.2. Using Water to Lower Contact Resistance.**



3.2.4.5. Potential measurement being influenced by foreign structures or different parts of the same structure (mixed potentials).

3.2.4.5.1. This occurs on all structures, where in the influence of potential gradients from other parts of the same structure.

- Part of structure in concrete.

- Part of structure in different type or aeration of soil.

- Part of structure made of different metals.

  - Dresser couplings.

  - Galvanized or high strength steel connector or elbow.

3.2.4.5.2. This occurs on all non-isolated structures, where in the influence of potential gradients from other structures. Recognize this error when near other structures. For example, copper, cast iron, or galvanized piping or grounds.

3.2.4.6. For full details about these five errors, see MIL HDBK 1136.

**3.3. Practical Measurement of CP Potentials.** The method used for potential testing varies widely for different types of structures and for the different criteria used for evaluation of the potentials taken. Sometimes different criteria may be used for different areas on the same structure.

3.3.1. The test method used depends first on the criteria which is being used to evaluate the adequacy of the CP applied to the structure. The criteria selected depends mostly on the type of the structure; isolation/non-isolation of the structure; structure coating type and efficiency; the type of CP system; the soil resistivity; the amount of current supplied by the CP system, and the instrumentation available for testing.

3.3.2. Galvanic CP System Criteria Selection: Generally, the criteria normally used is the -0.85 on criteria. Galvanic systems are normally used in low soil resistivities, with a low current requirement, very small driving voltage, and have a very small amount of current flow.

3.3.2.1. Consideration of the IR error must be made.

3.3.2.1.1. This is usually accomplished by placement of the reference electrode as near to the structure as possible (directly over the pipeline or tank) and as remote as possible from any galvanic anode.

3.3.2.1.2. This, combined with knowledge of the structure coating, soil resistivity, the size and spacing of the anodes and the anode current, is usually sufficient in determining the adequacy of the CP applied to the structure.

3.3.2.1.3. If doubt exists, or for questionable potential readings, use other criteria or excavate to allow the reference electrode to be placed as close as practical to the structure to further minimize IR error.

3.3.2.2. Use alternative criteria if

3.3.2.2.1. The dielectric strength of the structure coating is not good.

3.3.2.2.2. The soil resistivity is relatively high.

3.3.2.2.3. The location or spacing of the anodes makes it impossible to measure the structure potential remote from the anodes.

3.3.2.3. For very small and well coated structures (such as valves, elbows, tie-downs, etc.), the 100 mV polarization criteria should be used.

3.3.2.4. If the system is designed to allow interrupting the current from all anodes simultaneously, the 100 mV polarization criteria should be used.

3.3.2.5. The -0.85 instant off criteria is not attainable in many soil conditions with galvanic anodes.

3.3.2.5.1. Unless the native potential of the structure is very high and/or the soil resistivity is very low.

3.3.2.5.2. The -0.85 instant off criteria should not be used for galvanic CP systems except in rare cases. The 100 mV shift criteria or the -0.85 on criteria (considering IR) should be used.

### 3.3.3. Impressed Current CP System Criteria Selection.

3.3.3.1. For distributed anode impressed current systems:

3.3.3.1.1. The 100 mV polarization criteria may be the easiest to use.

3.3.3.1.2. The -0.85 instant off may be used.

3.3.3.1.3. The -0.85 on criteria (considering IR) should not be used.

3.3.3.2. For remote anode impressed current systems:

3.3.3.2.1. Any criteria, or a mixture of criteria may be used.

3.3.3.2.2. For structures with a high dielectric strength coating, the -0.85 instant off criteria may be the easiest to use; the 100 mV polarization criteria may be used. The -0.85 on criteria (considering IR) should not be used.

3.3.3.2.3. For structures which are bare, poorly coated, or have a deteriorated coating, the 100 mV polarization criteria may be the easiest to use; the -0.85 instant off criteria may be used. The -0.85 on criteria (considering IR) should not be used.

3.3.3.2.4. If the electrolyte resistivity is low, the dielectric strength of the coating is high, and the circuit resistance of the CP system is low. The -0.85 on criteria (considering IR error) is sufficient. Consideration of the IR error must be made. This is usually accomplished by placement of the reference electrode as near to the structure as possible (directly over the pipeline or tank). This, combined with knowledge of the structure coating, soil resistivity, the size and location of the anodes, and amount of anode current, is sufficient in determining the adequacy of the CP applied to the structure. If doubt exists, or for questionable potential readings, use other criteria or excavate to allow the reference electrode to be placed as close as practical to the structure to further minimize IR error.

3.3.4. Test Methods for the -0.85 on criteria:

3.3.4.1. A single electrode potential survey is conducted using any high impedance or high input resistant voltmeter (10 megaohms or higher) or data logger.

3.3.4.1.1. Connect meter as previously described.

3.3.4.1.2. Use proper reference electrode as previously described.

3.3.4.1.3. See paragraph 3.4 for information and potential measurement limits.

3.3.4.2. Since these potential readings are taken with the CP current on, there are errors in the measurement which must be considered to obtain a valid conclusion that adequate CP.

3.3.4.3. Consideration is understood to mean the application of sound engineering practice in determining the significance of voltage drops by methods such as:

3.3.4.3.1. Measuring or calculating the voltage drop(s).

3.3.4.3.2. Reviewing the historical performance of the CP system.

3.3.4.3.3. Evaluating the physical and electrical characteristics of the pipe and its environment.

3.3.4.3.4. Determining whether or not there is physical evidence of corrosion.

3.3.4.4. Also, consideration of all five errors (previously listed) must be made.

3.3.4.5. Interruption of the CP current does not fall under this criteria, since that would pertain to the -0.85 instant off or the 100 mV polarization criteria.

3.3.4.6. Measuring or calculating the voltage drop(s) include measuring all the factors which affect the magnitude of the voltage errors present in the on reading such as:

3.3.4.6.1. The anode output (rectifier current output).

3.3.4.6.2. The structure coating efficiency.

3.3.4.6.3. The location of the reference cell in relation to the anodes and the structure.

3.3.4.6.4. The electrolyte resistivity.

3.3.4.6.5. Comparison to previous potentials (native, on, and/or instant off).

3.3.4.7. Implementation of this criteria is only possible when these factors can be quantitatively verified by measurement or historical evidence that these factors have been considered.

3.3.4.8. Factors which decrease magnitude of the voltage drop errors or otherwise reduce the corrosion rate:

3.3.4.8.1. High dielectric strength coating.

3.3.4.8.2. Low electrolyte resistivity.

3.3.4.8.3. High pH (7 to 13), (except lead or aluminum structures).

3.3.4.8.4. Low temperatures lower the corrosion rate.

3.3.4.8.5. Low current density.

3.3.4.8.6. Non-existence of bimetallic connections (isolated structures).

3.3.4.8.7. Non-existence of interference corrosion.

3.3.4.8.8. Shallow and uniform pipe depth.

3.3.5. Test Methods for the -0.85 instant off criteria:

3.3.5.1. This criteria requires the measurement of the potentials when there is no CP current flowing.

3.3.5.2. For various methods used to measure the instant off potential see MIL HDBK 1136 section 7.2.5, Instant Off Test Methods which include:

3.3.5.2.1. Simultaneous interruption of all anode current (normally at the rectifier) and use of a meter which records hi/low readings (or recording second flash of a digital meter) and manually recording measurements.



3.3.5.2.2. Simultaneous interruption of all anode current (normally at the rectifier) and use of a data logger and extracting measurement manually from the database or by use of appropriate software.

3.3.5.2.3. Use of pulse generators and a waveform analyzer.

3.3.5.2.4. Simultaneous use of a high speed data logger and filtered oscilloscope to record the potential when the current is at zero.

3.3.5.2.5. If the instant off potential measurement meets or exceeds -0.85 Volts DC (using a copper/copper sulfate reference electrode), this criteria has been met. Other reference electrodes must be corrected to the factor for a copper/copper sulfate reference to be valid under this criterion.

3.3.6. Test Methods for the 100 mV polarization criteria:

3.3.6.1. The test method for this criteria is similar to the negative 0.85 instant off criterion, with the additional requirement of comparing the instant off reading to a native or depolarized reading.

3.3.6.2. For unprotected isolated structures:

3.3.6.2.1. Perform a thorough native survey and identify the most anodic area (highest negative) reading.

3.3.6.2.2. Determine the instant off reading required to meet the 100 mV shift criterion at that point (example, if the most negative reading was -0.625 Volts DC, the instant off would have to be -0.725 Volts DC).

3.3.6.2.3. Apply that instant off criterion to the entire structure.

3.3.6.3. For unprotected structures that are not isolated:

3.3.6.3.1. Perform a thorough native survey and identify the most anodic areas (highest negative) readings. If those readings are unusually high (over

-0.700 volts DC), annotate those exact locations; add 100 mV to those readings; or compare future instant off readings to those specific readings at those specific locations. If a significant percentage of the pipeline is over -0.700 Volts DC, consider using the -0.85 instant off criterion for the entire pipeline.

3.3.6.3.2. Determine the instant off reading required to meet the 100 mV shift criterion for the rest of the structure (example, if the most negative reading for the rest of the structure was -0.603 Volts DC, the 100 mV instant off would have to be -0.703 Volts DC).

3.3.6.3.3. Apply that instant off criteria to the rest of the structure.

3.3.6.4. For protected structures:

3.3.6.4.1. If native survey data is available, analyze data and use procedures as above for unprotected isolated or non-isolated structures, as appropriate.

3.3.6.4.2. If native survey data is not available, is incomplete or otherwise not useful, consider using the other criteria.

3.3.6.4.3. To use the 100 mV shift criterion after CP has been applied, the structure must be depolarized, to obtain an approximation of the native potential, and use procedures as above for unprotected isolated or non-isolated structures, as appropriate. After current interruption, considerable time may be required before the potential returns to an approximation of the native potential value:

60 to 90 days for typical well-coated buried structures.

2 to 30 days for buried structures with poor or no coating.

90 to 150 days for water tank interiors with good coatings and little or no water circulation.

3.3.6.4.4. Certain soil conditions may slow or speed depolarization, generally, the higher the corrosion rate, the quicker the depolarization occurs. Some factors, such as high levels of oxygen, movement or agitation of the electrolyte (flowing water) will speed depolarization. Some factors, such as

structure coatings, high resistivity soil, low levels of oxygen, and soils which seal the structure from water and oxygen will slow depolarization. Considerably more current is required to polarize the structure to a level where the 100 mV depolarization will occur in a relatively short time period (seconds or minutes).

3.3.6.4.5. If the instant off potential is 100 mV more negative than the native potential (or depolarized) potential, this criterion has been met.

#### **3.4. Structure-to-Soil Potential Limits.**

3.4.1. Excessive CP current produces hydrogen gas evolution at the surface of the cathode:

3.4.1.1. If the gas is produced faster than it can permeate out through the coating, bubbling of the coating will occur.

3.4.1.2. The amount of coating damage is dependent on the amount of gas generated and the type of coating.

3.4.1.3. The "on" potentials have many errors in the measurement (five sources of errors previously discussed).

3.4.2. All potentials discussed in this section are in reference to a copper/copper sulfate reference electrode. For other reference electrodes, make proper correction to interpret the measurement.

3.4.3. For water storage tanks:

3.4.3.1. Coatings used in water tanks disbond very easily as compared to coatings used on underground structures.

3.4.3.2. Note that silver/silver chloride reference electrodes potential varies as the chloride content of the electrolyte changes (reference).

3.4.3.3. "On" potential measurements over -1.10 volts DC could cause coating damage and "instant off" potentials should be taken (according to the magnitude of errors in the reading).

3.4.3.4. "On" potential measurements over -1.50 volts DC should be expected to cause coating damage and "instant off" potentials must be taken.

3.4.3.5. The instant off potentials must never exceed -1.10 volts DC.

3.4.4. For underground structures:

3.4.4.1. Coatings for underground structures are generally more resistant to damage from excessive CP current.

3.4.4.2. The only true way to measure the possibility for coating damage is with an error free measurement (see paragraphs 3.2 and 3.3).

3.4.4.3. Instant off measurements should be used whenever possible:

3.4.4.3.1. Instant off measurements over -1.22 volts DC are not theoretically possible. Look for other DC current sources.

3.4.4.3.2. Synchronous interruption of all current sources must be accomplished.

3.4.4.4. For fusion bonded coatings the instant off potentials should not exceed -1.07 volts DC and must never exceed -1.12 volts DC.

3.4.4.5. For Coal Tar coatings the instant off potentials should not exceed  
-1.12 volts DC and must never exceed -1.20 volts DC.

3.4.4.6. For Plastic Tape coatings the instant off potentials should not exceed -1.02 volts DC and must never exceed -1.07 volts DC.

3.4.4.7. For other coatings refer to specifications for cathodic disbondment properties compared to above coatings.

3.4.4.8. For uncoated structures there is theoretically no potential limit. Instant off readings over -1.00 generally waste power and anode material.

3.4.4.9. Table 3.1 assumes an IR drop error and is given for information only.

3.4.4.9.1. "On" potential should be suspected of coating damage if over the potentials listed in table 3.1, "SUSPECTED column", and "instant off" potentials should be taken.

3.4.4.9.2. Coating damage should be expected when the potential measurement is over the potential listed in table 3.1, "EXPECTED column", and "instant off" potentials must be taken.

**Table 3.1. "On" Potential and Coating Damage.**

<b>SOIL RESISTIVITY</b>	<b>SUSPECTED</b>	<b>EXPECTED</b>
2,000	-1.20	-1.80
3,000	-1.30	-2.20
5,000	-1.40	-2.50
10,000	-1.60	-2.70
15,000	-1.75	-2.75
20,000	-1.90	-3.00
30,000	-2.05	-3.30
40,000	-2.20	-3.60
50,000	-2.35	-3.90
100,000	-2.60	-4.40

### **3.5. Cell to Cell Potential Testing Procedures.**

3.5.1. Cell to cell potential testing is performed to determine the direction of current flow in the earth:

3.5.1.1. This is especially useful on unprotected pipelines to locate anodic areas on the pipeline. These procedures are not normally used on protected structures.

3.5.1.2. On unprotected pipelines when CP of the complete line is not feasible or economical, "hot spot protection" is sometimes used. This test procedure is used to identify the anodic areas of the pipeline for application of CP to those locations.

3.5.1.3. The polarity of the voltage difference between the two reference cells indicates the direction of current flow.

3.5.2. The accuracy of the reference electrodes (half cells) used to take cell to cell measurements must be determined:

3.5.2.1. The accuracy of the two half cells is determined by measuring the difference in potential between the two half cells being used for the test. Use a suitable high input resistance voltmeter on the millivolt scale, place the two cells cone to cone, and measure the potential difference. The potential difference should not be in excess of 5 mV.

3.5.2.2. Perfect matching of the two reference cells is desirable. If perfect matching is not possible, the error must be accounted for in all measurements taken.

3.5.2.3. Equal spacing between the reference cells must be made to evaluate any magnitude differences in measurements.

3.5.2.4. Polarity of the measurements is critical. Notes should be made of all changes in polarity.

### **3.6. Rectifier Efficiency Testing Procedures.**

3.6.1. The efficiency of a rectifier is determined by:

3.6.1.1. Measuring the output voltage.

3.6.1.2. Measuring output current.

3.6.1.3. Calculating the input in watts (revolutions per hour of the KWH meter disc X PF (Power Factor) shown on the face of the KWH meter).

3.6.1.4. And using the following formula:

$$\text{Rectifier Efficiency} = \frac{\text{Output Current X Output Voltage}}{\text{Input Watts}}$$

3.6.2. An alternate procedure to determine the rectifier efficiency if there is no KWH meter or known Power Factor:

3.6.2.1. Measuring the output voltage.

3.6.2.2. Measuring output current.

3.6.2.3. Obtain the input watts is by:

3.6.2.3.1. Measure the AC input voltage.

3.6.2.3.2. Measure the AC input current by using an accurate clamp-on ammeter (preferred) or disconnecting and measuring with an ammeter. Assume a PF of 90% and use the following formula:

$$\text{Rectifier Efficiency} = \frac{\text{Output Current X Output Voltage}}{\text{Input Current X Input Voltage X .9}}$$

3.6.2.4. This method assumes the power factor (usually between 85% and 95%):

3.6.2.4.1. Will not be truly accurate.

3.6.2.4.2. Will give a reasonable approximation.

3.6.2.4.3. If this method is used, subsequent efficiency testing should be done in the same manner to obtain comparable results.

3.6.2.5. The expected efficiency of a rectifier depends on:

3.6.2.5.1. The type of AC power (Single or Three Phase). Three phase units are much more efficient.

3.6.2.5.2. The type of rectifying elements (Selenium or Silicon). Silicon units are more efficient.

3.6.2.5.3. The type of rectifier (Bridge or Center tap).

3.6.2.5.4. The percent of load of the unit. Units are most efficient at full rated output.

3.6.3. A change in rectifier efficiency indicates problems with the rectifier unit.

### **3.7. Dielectric Testing Procedures.**

3.7.1. Do not use an ohmmeter to measure resistance of an installed dielectric:

3.7.1.1. An ohmmeter should never be used on a live circuit. A good dielectric may have a significant voltage present, and should be considered a live circuit.

3.7.1.2. If the dielectric is good, and the two sides have a voltage difference, current will flow through the ohmmeter and could damage the ohmmeter:

3.7.1.2.1. The measurement would not indicate a resistance value because the voltage difference would be added or subtracted from the internal battery voltage measured (according to polarity).

3.7.1.2.2. A totally erroneous (or even negative) measurement would result.

3.7.1.3. If the dielectric is good, and the two sides have no significant voltage difference, there would be little or no current flow through the ohmmeter:



3.7.1.3.1. The measurement would indicate a sum of the resistance to earth of the structures on both sides of the dielectric.

3.7.1.3.2. According to the size and coating of the structures involved, this could be from less than 1 ohm to several thousand ohms, and does not give any indication of the resistance across the dielectric.

3.7.2. Testing an installed dielectric presents several problems:

3.7.2.1. Since typical installations normally include many dielectrics, all of which are in a parallel circuit, failure of one dielectric can effectively short the entire system.

3.7.2.2. There are indications of the shorted condition of one dielectric at many, or all, other dielectrics installed.

3.7.2.3. Some methods for testing a dielectric look for a voltage difference across the two sides, which is an indication of that dielectrics condition:

3.7.2.3.1. If voltage is detected, the dielectric is not shorted.

3.7.2.3.2. If voltage is not detected, the dielectric may be shorted. Further testing is required to verify the condition.

3.7.2.3.3. Use of the headset type of insulation tester (similar to Tinker & Razor model "IT"). If tone is heard, voltage is present the dielectric is not shorted. If tone is not heard, voltage is not detected (see above).

3.7.2.3.4. Use of a multimeter to measure a mV difference. Range should be on Auto (mV range is typically 300mV, which could easily be exceeded across a good dielectric). If meter is not auto-ranging, select high range for initial measurement and change ranges until best resolution is achieved. A measurement over 10 mV indicates the dielectric is not shorted. A measurement under 10 mV is inconclusive (see above).

3.7.2.3.5. Compass: Place a magnetic type compass on the dielectric. If compass aligns with the direction of the pipe, voltage is present and the dielectric is shorted. If compass does not align, voltage is not detected (see above). Sometimes a 6 or 12 volt battery is connected to the circuit as an additional voltage difference, and the test repeated.

3.7.2.3.6. Use a clamp-on DC milliammeter with properly sized clamp for pipeline being tested. Place clamp next to pipe, zero meter, and clamp around pipe at the dielectric. If measurement is over 10 milliamps, dielectric is shorted. If measurement is under 10 milliamps, dielectric **may** not be shorted.

3.7.2.4. Only one method gives a totally reliable indication of an installed dielectric (figure 3.3):

**Figure 3.3. Using a Radio Frequency Tester.**



3.7.2.4.1. The insulated flange tester (radio frequency tester) gives an accurate indication of the specific dielectric being tested because of its wave length, the strength of the signal and use of the "skin effect" (most of the signal travels on the surface of the dielectric).

3.7.2.4.2. This method will not read through other parallel paths, even when these paths are in the immediate vicinity. Therefore, this method should be used for testing when any other method is not conclusive.

3.7.3. The preferred method to determine if a dielectric may be shorted is by structure to earth potential testing:

3.7.3.1. This method will provide an immediate indication if the dielectric is not shorted. At the same time it will provide valuable potential data. Determine if there may be another dielectric in the area which is shorted.

3.7.3.2. Take a potential measurement of both sides of the installed dielectric (figure 3.4). Change only the structure connection. Do not move the reference electrode.

**Figure 3.4 Taking Potentials to Test Installed Dielectric.**



3.7.3.3. If the two potential measurements are significantly different (over 10 mV), the dielectric is good:

3.7.3.3.1. The street (protected) side of the dielectric should be at a potential more negative than -0.85 Volts DC.

3.7.3.3.2. The house (unprotected) side of the dielectric should be between approximately -0.15 Volts DC and -0.55 Volts DC .

3.7.3.3.3. If the dielectric is good and the house side of the dielectric has a potential more negative than expected (for example, if the house side potential reading is over -0.65, with a street side potential more negative), another shorted dielectric in the area should be suspected. Further investigation is required.

3.7.3.4. If the two potential measurements are not significantly different (under 10 mV), the dielectric may be shorted. The insulated flange tester should be used.

3.7.4. Using insulated flange tester, there are two different type units: Above Ground Insulator Tester (can also be used to test individual bolts on isolated flanges) and Buried Insulator Tester. Use each type only for it's intended application.

3.7.4.1. There are two different models of each type of insulated flange tester.

3.7.4.1.1. Tester with "zero"/"test" switch and control knob. Turn Insulated Flange Tester "zero"/"test" switch to "zero". Turn control knob on. Using control knob, zero needle indicator to full scale (100). Turn "zero"/"test" switch to "test". Without adjusting control knob, test dielectric. You must make good contact to metal on both sides of the dielectric. No needle movement indicates good dielectric (stays at full scale). Needle movement indicates bad dielectric.

3.7.4.1.2. Tester without switch or control knob. To test dielectric, you must make good contact to metal on both sides of dielectric. For underground model, hold contact for at least 20 seconds. An audible signal is heard when test cycle is completed. No change in LCD display and no change in audible signal indicates good dielectric.

3.7.4.2. Using a long wave length signal (low frequency) pipe locator:

3.7.4.2.1. Install signal transmitter on pipeline.

3.7.4.2.2. Ensure low resistance isolated ground for transmitter.

3.7.4.2.3. Use pipe locator and attempt to follow signal past dielectric. If signal stops at dielectric, dielectric may not be shorted. If signal can be followed past dielectric, dielectric is shorted.

3.7.4.3. Using a fault detector and the signal from an impressed current system (DC output has a 120-cps component, sometimes called "pulsating DC").

3.7.4.3.1. This method can only be used with impressed current systems with a single phase rectifier, and works best with no output choke or filter (stronger signal).

3.7.4.3.2. Must use a fault detector (such as the Pipe Horn Model 200FDAC) or a pipe locator (with built in fault detector) capability of following a 120-cps signal.

3.7.4.3.3. Installation of a current interrupter on the rectifier will ensure that fault detector is following the impressed current signal. Electrical lines produce a 120-cps harmonic which can also be followed with a fault detector.

3.7.4.3.4. Use fault detector to follow signal on pipeline to the dielectric.

3.7.4.3.5. Use fault detector and attempt to follow signal past dielectric. If signal stops at dielectric, dielectric may not be shorted. If signal can be followed past dielectric, dielectric is shorted.

3.7.4.4. Other methods to make dielectric testing easier:

3.7.4.4.1. If possible, merely increase the current level of the existing CP system. This will serve to increase the difference across good dielectrics, making it easier to test. This will also increase the signal available for most other methods of dielectric testing. Repeat the dielectric testing.

3.7.4.4.2. Installation of a temporary local CP system (or battery across dielectric). This may greatly increase the current to the street side of the dielectric, making it easier to test. The temporary system should be installed so that the current will be applied to the location being tested. Repeat the dielectric testing.

3.7.4.4.3. Use a multi-combination meter, continuity check circuit. Connect test leads to the meter left terminals. Temporarily short test lead ends together, turn contact check circuit on, zero needle to full scale, and disconnect test leads. Connect one test lead to street (protected) side of dielectric. Connect one test lead to house (unprotected) side of dielectric. A full scale deflection indicates shorted dielectric. Use insulated flange tester to verify specific dielectric.

A deflection of 75% to almost full scale deflection, or deflection past 100% (or pegged) is inconclusive. Reverse test lead connections: same reading indicates there may be a bad dielectric in the area or that the dielectric is partially shorted. Use insulated flange tester to verify specific dielectric. Opposite side of full scale reading indicates dielectric is good, for example, 90% reading, when leads are reversed pegs, or pegged reading reversed, reads 90%. Use other test procedure to verify dielectric condition.

Deflection from 30% to 75% is inconclusive. Could be bad dielectric in the area. Use other test procedure to verify dielectric condition.

Deflection under 30% indicates all dielectrics in the area are good (structures are isolated).

### **3.8. Casing Test Procedures.**

3.8.1. Testing casings is very similar to testing dielectrics:

3.8.1.1. Do not use an ohmmeter to measure between a casing and the carrier pipeline:

3.8.1.1.1. An ohmmeter should never be used on a live circuit. A good casing isolation may have a significant voltage present, and should be considered a live circuit. If the casing isolation is good, current will flow through the meter and could damage the meter.

3.8.1.1.2. The measurement would not indicate a resistance value. The voltage difference would be interpreted as coming from the internal battery instead of the external electrical circuit being measured. A totally erroneous (or even negative) measurement would result.

3.8.1.2. Shorted casings present serious problems to the application of CP to the carrier pipe.

3.8.1.2.1. They totally shield the carrier pipeline inside the casing from receiving any CP.

3.8.1.2.2. They “steal” current which would otherwise protect a large area of the pipeline outside the casing. Casings are normally not coated (or poorly coated). Have a relatively low resistance to earth (than the coated carrier pipeline). Provide a lower resistant path for CP current.

3.8.2. Casing test stations normally have four wires: two to the casing; two to the carrier pipeline. If there is not a test station already installed, one should be installed prior to testing. At a minimum, there must be a metallic connection made to the carrier pipeline and a vent pipe which is connected to the casing. If there is no vent pipe or carrier pipe test point in the vicinity of the casing, excavation must be made to the carrier pipeline or the casing, as required, and test connections made.

3.8.3. Use a suitable insulated flange tester (for testing underground isolations). Follow the same procedures listed previously for testing a dielectric.

3.8.4. Testing a casing with CP on the carrier pipeline:

3.8.4.1. Take a potential measurement of the carrier pipeline.

3.8.4.2. Take a potential measurement of the casing. Do not change the location of the reference electrode.

3.8.4.3. If the two potential measurements are significantly different (over 10 mV), the casing is not shorted to the pipeline. Under normal conditions the carrier pipeline should be at a potential more negative than -0.85 Volts DC. The casing should be between approximately -0.35 and -0.65 Volts DC. If casing is galvanized, it could be as high as -1.1 Volts DC.

3.8.4.4. If the two potential measurements are not significantly different (under 10 mV), the casing may be shorted to the pipeline. One of the following additional tests may be made:

3.8.4.4.1. If possible, increase the current level of the existing system or install a temporary local CP system to increase the current to the carrier pipeline. The temporary CP system must be installed on the opposite side of the crossing from the location of the potential testing. The potential shift which occurs when the CP system is interrupted may also aid in determining if the casing is isolated.

3.8.4.4.2. Repeat potential measurement of the carrier pipeline and the casing. If the potential of the casing shifts positive when the current increases or turns on, the insulation is good. If the potential of the casing shifts negative when the current increases or turns on, the casing may be shorted.

3.8.4.4.3. Use a suitable insulated flange tester (see above).

3.8.5. Testing a casing without CP on the carrier pipeline.



3.8.5.1. Use an insulated flange tester suitable for testing underground dielectrics. Follow the same procedures listed previously for testing a dielectric.

3.8.5.2. Install a temporary local CP system to apply current to the carrier pipeline. Test the same as the casing with CP on carrier pipeline (see above).

3.8.5.3. Use a multi-combination meter, continuity check circuit.

3.8.5.3.1. Connect test leads to the meter left terminals. Temporarily short test lead ends together; turn contact check circuit on; zero needle to full scale, and disconnect test leads.

3.8.5.3.2. Connect one test lead to casing.

3.8.5.3.3. Connect one test lead to carrier pipeline. Full scale deflection indicates the casing is shorted to the carrier pipeline.

Deflection of 75% to almost full scale deflection, or deflection past 100% (or pegged) is inconclusive. Reverse test lead connections. Same reading indicates there may be a partial short. Use underground insulated flange tester to verify. Opposite side of full scale reading indicates casing isolation is good. For example, a 90% reading, when leads are reversed, reads over 100% (pegs), or a reading over 100% (pegged) when leads are reversed, reads under full scale.

Deflection from 30% to 75% is inconclusive: could be partial short. Reverse leads and test as above. Use other test procedure to verify casing condition.

Deflection under 30% indicates good isolation.

### **3.9. Testing for a Short Between Two Structures.**

3.9.1. Testing for a short is similar to dielectric and casing testing.

3.9.1.1. Do not use an ohmmeter to measure between two structures.

3.9.1.1.1. An ohmmeter should never be used on a live circuit. Two structures which are isolated may have a significant voltage difference, and should be considered a live circuit. If the structures are isolated, current will flow through the meter and could damage the meter.

3.9.1.1.2. The measurement would not indicate a resistance value. The voltage would be interpreted by the meter as coming from the internal battery instead of the external electrical circuit being measured. A totally erroneous (or even negative) measurement would result.

3.9.1.2. Use a multi-combination meter, continuity check circuit:

3.9.1.2.1. Connect test leads to the meter left terminals. Temporarily short test lead ends together; turn contact check circuit on; zero needle to full scale, and disconnect test leads.

3.9.1.2.2. Connect one test lead to casing.

3.9.1.2.3. Connect one test lead to carrier pipeline. Full scale deflection indicates the two structures are connected.

Deflection of 75% to almost full scale deflection, or deflection past 100% (or pegged) is inconclusive. Reverse test lead connections. Same reading indicates there **may** be a partial short between the structures. Other testing should be conducted to verify. Opposite side of full scale reading indicates structures are isolated. For example a 90% reading, when leads are reversed, reads over 100% (pegs), or a reading over 100% (pegged) when leads are reversed. reads under full scale.

Deflection from 30% to 75% is inconclusive. Could be a partial short in the area. Reverse leads and test as above. Use other test procedure to verify.

Deflection under 30% indicates the structures are isolated.

3.9.2. Testing for a short between two structures with CP on one structure:

3.9.2.1. Take a potential measurement of both structures. Do not move the reference electrode.

3.9.2.2. If the two potential measurements are significantly different (over 10 mV), the two structures are not shorted.

3.9.2.2.1. Under normal conditions the structure with CP should be at a potential more negative than -0.85 Volts DC.

3.9.2.2.2. A steel structure without CP should be between approximately -0.35 Volts DC and -0.65 Volts DC.

3.9.2.2.3. Copper or steel in concrete structures should have a potential between approximately -0.20 Volts DC and -0.30 Volts DC.

3.9.2.2.4. Galvanized steel structures which are isolated, could have a potential as high as -1.10 Volts DC.

3.9.2.2.5. Galvanized steel structures can be shorted to cast iron, brass, copper or steel structures, resulting in a mixed potential (-.40 to -1.0 Volts DC).

3.9.2.3. If the two potential readings are not significantly different (under 10 mV):

3.9.2.3.1. The two structures may be shorted. Additional testing is required. Install a temporary local CP system to increase the current to the protected structure or, if possible, merely increase the current level of the existing system.

3.9.2.3.2. Install the temporary system to distribute current to just one structure.

3.9.2.3.3. Repeat the potential measurement of both structures. If the potential of the unprotected structure remains approximately the same or changes in a positive direction (less negative), when the potential of the

protected structure changes in a negative direction, they are not shorted. If both potential measurements change more negative as current is increased, the two structures are shorted together.

3.9.2.3.4. Interruption of the CP current may make it easier to test continuity. If the potential of the unprotected structure shifts positive when the rectifier is interrupted, they are isolated. If the potential of the unprotected structure shifts negative when the rectifier is interrupted, they may be shorted.

3.9.3. Testing for a short between two structures with CP on both structures.

3.9.3.1. Take a potential measurement of both structures. Do not move the reference electrode.

3.9.3.2. If the two potential measurements are significantly different (over 10 mV), the two structures are not shorted in the area. Under normal conditions both structures should be at a potential more negative than -0.85 Volts DC.

3.9.3.3. If the two potential measurements are not significantly different (under 10 mV).

3.9.3.3.1. The two structures may be shorted. Additional testing is required.

3.9.3.3.2. If one or both of the protected structures have impressed current systems, turn off the rectifier on one system or install a current interrupter on one system.

3.9.3.3.3. Repeat the potential measurement of both structures. If structures are isolated, the structure with the CP current off changes significantly in the positive direction (less negative). The structure with the CP current still on remains the same. If structures are shorted, the structure with the CP current off changes slightly in the positive direction. The structure with the CP current still on changes slightly in the positive direction.

3.9.3.3.4. If both systems have impressed current systems and a clear indication of the shorted condition has still not been identified. Repeat

previous test procedure leaving the other systems rectifier on and repeat testing. Turn off both rectifiers and use radio frequency insulation tester or multi-combination meter continuity check circuit (see procedures above).

3.9.4. Testing for a short between two structures without CP on either structure.

3.9.4.1. Use radio frequency insulation tester (see procedures above).

3.9.4.2. Use multi-combination meter continuity check circuit (see procedures above).

3.9.4.3. Take a potential measurement of both structures. Do not move the reference electrode.

3.9.4.4. If the two potential measurements are significantly different (over 10 mV), the two structures are not shorted. Under normal conditions both structures should be at a potential between approximately -0.35 Volts DC and -0.65 Volts DC.

3.9.4.5. If the two potential measurements are not significantly different (under 10 mV).

3.9.4.5.1. The two structures may be shorted. Additional testing is required.

3.9.4.5.2. Install a temporary local CP system to apply current to the one structure. Repeat the potential measurement of both structures. If structures are isolated, the structure with the CP current will change significantly in the negative direction. The structure with no CP current remains approximately the same. If structures are shorted, both structures change in the negative direction.

### **3.10. Current Requirement Testing Procedures.**

3.10.1. Current requirement testing is used when planning a CP system installation. This testing will determine the type and size of the CP system required.

3.10.2. If the system design requires isolation of the structure to be protected, that isolation must be accomplished prior to the current requirement test. The current requirement for a non-isolated structure does not give any indication of what the current requirement would be if the structure were isolated.

3.10.3. Temporary systems are used to determine the effect of current applied on the potential of the structure being tested.

3.10.4. Actual protection need not be accomplished to estimate the amount of current required.

3.10.4.1. Portable rectifiers should be used in conjunction with temporary anodes (usually ground rods) or existing metallic structures to impress a test current to the structure.

3.10.4.2. Vehicle batteries can be used, as well as spare rectifiers, DC generators, DC welding units, or rectifiers from other systems can be temporarily removed for use.

3.10.5. Temporary local CP systems should be located in areas where the intended installation is to be located, if known:

3.10.5.1. If not known, they should be located as remote as possible from the structure to be protected.

3.10.5.1.1. Without any foreign structures in the area of the temporary anode bed.

3.10.5.1.2. Without any foreign structure between the temporary anode bed and the structure under test.

3.10.5.2. The area of the temporary installation should be well scouted to determine if any possible temporary anodes exist or if any foreign structures are in the area:

3.10.5.2.1. Existing metallic structures, such as metal fences, culverts, abandoned pipelines, or abandoned wells can be used as temporary anodes or to supplement installed temporary anodes.

3.10.5.2.2. Do not use any metallic structure for a temporary anode which is shorted to the structure being tested. Large current surges which can cause injury to personnel and damage to equipment would result. Test temporary anode for continuity to structure under test (see testing for continuity between two structures).

3.10.5.2.3. Do not use active pipelines or tanks for temporary anodes. Corrosion may occur that could cause leaks.

3.10.5.3. The number of temporary anodes required depends on:

3.10.5.3.1. The available voltage source.

3.10.5.3.2. Availability and size of existing metallic structures which may be used.

3.10.5.3.3. The size of the structure being tested.

3.10.5.3.4. The coating efficiency of the structure being tested.

3.10.5.3.5. The amount of current desired.

3.10.5.3.6. The resistivity of the soil.

3.10.5.3.7. Generally, temporary anodes should be spaced from 15 to 25 feet apart. If temporary anodes are close together (0 to 8 feet), will be reduced benefit from adding additional anodes.

3.10.5.3.8. If the number of anodes is doubled, the amount of current will be approximately doubled (with adequate spacing).

3.10.5.3.9. If the soil resistivity is doubled, the number of temporary anodes required is doubled. In very low resistivity soil, two or three temporary anodes may be sufficient. In very high resistivity soil, a high number of temporary anodes may be required.

3.10.5.3.10. The better the coating of the structure being tested, the smaller the number of temporary anodes required. Very well coated structures will exhibit a noticeable potential change with a small amount of current (1 or 2 amps). Poorly coated structures will not exhibit a noticeable potential change except with a larger amount of current (10 to 20 amps).

3.10.5.3.11. If the voltage is doubled, the number of temporary anodes required will be approximately cut in half. If the voltage source is low (6 - 12 volts), more temporary anodes will be required. If the voltage source is high (60 to 120 volts), fewer temporary anodes are required.

3.10.5.3.12. In dry soil conditions (under 20% moisture), watering the anodes will lower the resistance (provide more current).

3.10.5.3.13. Streams, ponds, rivers, lakes, bays, oceans or other standing water make an ideal location for temporary anodes. The temporary anodes can be simply laid in the water.

3.10.5.3.14. To make temporary anodes, cut 8 or 10 foot ground rods in half. Sharpen one end. Use a ground rod driver to install into the ground. Use a ground rod puller to remove from the ground (see MIL HDBK 1136).

3.10.5.3.15. Metallic pipe or conduit may also be used.

3.10.5.3.16. In extreme cases, excavate 6 to 10 foot hole. Push small diameter steel pipe into the earth with a backhoe or bulldozer. This method can also be used to attempt to simulate a deeper installation. It is possible to



install temporary anodes 30 to 60 feet deep in this manner, if no rock formations are encountered.

3.10.5.4. The temporary anodes must all be connected to the positive terminal of the power source.

3.10.5.5. The structure being tested must be connected to the negative terminal of the power source.

3.10.5.6. For physical strength and low resistance, #6 AWG copper cable or larger must be used. No. 2 AWG or greater is desired, especially if long runs in either the structure or anode cable is required. Connections can be made with pipe clamps, ground rod connectors, test clamps, split bolts, and exothermic welding. All wire and connections must be made to accommodate the voltage and current required for the testing.

3.10.5.7. Before any power is applied, it is essential to obtain the as found potential data of the structure. The native potential must be tested for all locations to be tested during the current requirement test, to obtain the potential shift accomplished by the test current.

3.10.5.8. Beginning at a low voltage setting, turn power on. Ensure the potential shift of the structure is in the negative direction. Gradually increase voltage and current to desired output. Periodically check potential to ensure a corresponding negative shift occurs as current is increased. If maximum voltage is reached and more current is still required, turn system off. Supplement the temporary anode bed. Consider using multiple power sources and/or multiple temporary anode beds.

3.10.5.9. Sufficient current is applied when a substantial section of the structure to be tested has achieved a noticeable potential shift or when full protection is achieved.

3.10.5.10. If full protection is achieved, the current requirement is the same as the test current.

3.10.5.11. If full protection is not achieved, further calculations are required:

3.10.5.12. Once the potential shift is ascertained, and the current to get that shift is known, approximation of the actual current requirement can be calculated.

3.10.5.13. If the current is doubled, the potential shift can be expected to approximately double.

3.10.5.14. Current distribution should be considered. If good current distribution is achieved, a simple mathematical formula would produce the current requirement. If proper current distribution is not achieved with the temporary system, proper current distribution must be considered in the design.

3.10.5.15. If a current requirement test includes more than one anode bed location, all current sources should be interrupted simultaneously to measure the potential shift of the structure:

3.10.5.15.1. The total current requirement is found by adding the current from all power sources together.

3.10.5.15.2. Always consider proper current distribution and estimate the required current requirement for each individual system.

3.10.5.16. Upon completion of testing, turn all power sources off; disconnect all cables, and remove temporary anodes. For ease of removal of ground rods or small diameter pipes and conduit, use three flat metal bars as shown in MIL HDBK 1136.

### **3.11. Electrolyte Resistivity Measurement.**

3.11.1. The most common unit of resistivity is Ohm-centimeters.

3.11.2. Many factors in the operation of CP systems are dependent upon the resistivity of the electrolyte:

3.11.2.1. Resistance to earth of anodes is directly proportional to the resistivity of the electrolyte.

3.11.2.2. The corrosivity of the environment is higher when the resistivity is lower.

3.11.2.3. The output of both galvanic anodes and impressed current anodes is dependent upon the resistivity of the electrolyte.

3.11.3. Four Pin Method: The most commonly used means of measuring soil resistivity is by the four pin method.

3.11.3.1. In this method, a current is passed through two outer electrodes and a drop in potential through the soil due to the passage of the current is measured with a second pair of inner electrodes.

3.11.3.2. A specialized instrument is used to supply the current and measure the potential drop (figure 3.5).

3.11.3.3. In order to reduce the influence of any stray currents in the area, the instrument uses a unique 90 cycle square wave.

3.11.3.4. The electrodes should be arranged in a straight line, with equal spacing between all electrodes (figure 3.6).

3.11.3.5. The electrodes should be inserted into the ground at an equal depth, normally 4 inches.

**Figure 3.5. Soil Resistivity Testing Meters, Nilsson Model 400, Vibroground Model 263 and Model 293.**



**Figure 3.6. Using Four Pin Method to Measure Soil Resistivity.**



3.11.3.6. The soil resistivity is calculated from the indicated reading by using the following formula:

$$\text{Resistivity (Ohm-cm)} = 191.5 \times \text{pin spacing (in feet)} \times \text{meter reading.}$$

3.11.3.7. In this method, the average resistivity of the soil between the two center electrodes to a depth equal to the pin spacing is measured. Readings are normally taken at approximately 2.5', 5' and 10' (see chart below for using common multipliers). For multipliers for common distances and distances for even multipliers see table 3.2.

**Table 3.2. 4-Pin Soil Resistivity Measurement Reading Multipliers.**

For Common Distances:		For Even Multipliers:	
Rod Spacing	Multiplier	Rod Spacing	Multiplier
2' 6"	479	2' 7"	500
5'	958	5' 3"	1000
7' 6"	1,436	7' 10"	1,500
10'	1,915	10' 5"	2,000
12' 6"	2,394	13' 1"	2,500
15'	2,872	15' 8"	3,000
20'	3,830	20' 11"	4,000
30'	5,745	31' 4"	6,000
For Common Distances		For Even Multipliers (all in cm)	
75 cm	471.21	79.58	500
1 meter	628.28	159.16	1000
150 cm	942.42	238.75	1500
2 meters	1256.56	318.33	2000
3 meters	1884.84	397.91	2500
4 meters	2513.12	477.49	3000
5 meters	3141.40	636.66	4000
10 meters	6282.80	954.99	6000

3.11.3.8. If the reading is greater as the pin spacing is increased, the actual soil resistivity at the greater depth is greater than indicated.

3.11.3.9. If the average soil resistivity decreases at greater depths then the actual soil resistivity at that depth is lower than indicated.

3.11.3.10. To calculate approximate resistivities at depth use the Barnes Method formula (table 3.3). The Barnes method gives an approximation of the average resistivity for a specific depth range. The change in the reciprocal of the resistivity of two layers is used to estimate the lower level.

**Table 3.3. Barnes Method of Estimating Soil Resistivity Layers.**

As an example assume the following:

SPACING FEET	R <sub>1</sub> OHMS	SPACING FACTOR	RESISTIVITY OHM-CM	MHOS (1 / OHM-CM)
5	31.20	1000	31,200	0.0321
10	12.40	2000	24,800	0.0806
15	4.37	3000	13,100	0.2288
20	1.31	4000	5,250	0.7634

Using the Barnes method to calculate layer resistivity:

MHOS CHANGED	OHM-CM (1 / MHOS CHANGED)	SPACING FACTOR (5 foot layer)	LAYER RESISTIVITY OHM-CM	LAYER DEPTH IN FEET
-	-	-	31,200	0 - 5
0.0485	20.6	1000	20,600	5 - 10
0.1482	6.75	1000	6,750	10 - 15
0.5346	1.87	1000	1,870	15-20

**3.11.4. Two Pin Method.** In the two pin method the potential drop is measured between the same pair of electrodes used to supply the current. The equipment used to make this type of measurement is often called the "Shepard Canes" after its inventor. The probes are placed one foot apart. If the soil is too hard for the probes to penetrate the reading is taken at the bottom of two augured holes. The instrument is calibrated for a probe spacing of one foot and gives a reading directly in Ohm-cm. This method is:

3.11.4.1. Less accurate than the four pin method.

3.11.4.2. Measures the resistivity of the soil only near the surface.

3.11.4.3. Often used for preliminary surveys.

3.11.4.4. Quicker than using the four pin method.

**3.11.5. Other Methods (Soil Rod, Soil Box).** A soil rod is essentially a two pin resistivity measuring device where the electrodes are both mounted on a single rod. Like the other two pin method, the resistivity of the soil to a very shallow depth is measured. Also, the soil must be soft enough to allow penetration of the rod. Measurements using the soil rod can, however, be made quickly when making measurements in soft soil.

3.11.5.1. Soil samples can be taken and the resistivity of the sample can be determined by the use of a soil box.

3.11.5.2. The measurement made on the soil sample is essentially the four pin method.

3.11.5.3. Metal contacts in each end of the box are used to pass current through the sample.

3.11.5.4. Potential drop is measured across probes inserted into the soil.

3.11.5.5. The resistivity is calculated using constants furnished with the particular size of soil box being used.

3.11.5.6. Soil boxes are commonly designed with a multiplier of 1.

3.11.5.7. Soil box problems.

3.11.5.7.1. Due to the disturbance of the soil compaction will be different.

3.11.5.7.2. The sample may dry out during shipment.

3.11.5.7.3. To minimize drying out of samples they should be placed in plastic bags and sealed prior to shipment.

3.11.5.7.4. Less likely to represent true in place soil resistivity than an actual field test.

**3.12. pH Testing Procedures.** The pH of an electrolyte is a measure of the acidity or alkalinity of the electrolytic solution.

3.12.1. pH ranges from 0 to 14: 0-7 being acidic; 7 being neutral, and 7-14 being alkaline.

3.12.2. pH can be measured using several methods.

3.12.2.1. Antimony electrode test method. Antimony is a unique metal which has a direct relationship between the pH and its measured potential. The potential difference or voltage developed between antimony and a copper/copper sulfate reference electrode varies from approximately 0.1 volts DC to 0.7 volts DC due to variations in the pH. Consequently it can be used to determine the pH of the electrolyte when used in conjunction with this reference electrode.

3.12.2.2. The antimony electrode must be cleaned prior to each use. Special cleaning procedures must be used. Clean the antimony electrode as per instructions in MIL HDBK 1136, Cleaning of the Electrode. Antimony is very brittle, treat it carefully. The antimony tip must be kept smooth, there must be no rough surface or pits.



3.12.2.3. Place the antimony electrode and the copper/copper sulfate half cell in contact with the electrolyte and measure the potential difference using a high input resistance voltmeter.

3.12.2.4. The measurement takes several seconds to stabilize; this stabilization is much slower in acid solutions than in alkaline solutions.

3.12.2.5. Avoid taking these measurements with CP current on. Current flow in the electrolyte will affect the accuracy. If current flow cannot be stopped, place the two electrodes close together, perpendicular to the direction of current flow. To measure for the presence of any current flow in the electrolyte. Place one copper/copper sulfate half cell in the electrolyte. Place a second copper/copper sulfate half cell a few inches from the other reference cell. Measure the potential difference using a high input resistance voltmeter. Take measurements in several directions. If no current is present, the measurements will read the same. If current is present, the lowest measurement will be where the least amount of current is flowing.

3.12.3. Chemical test method: Chemical test methods are normally associated with liquid electrolyte samples.

3.12.3.1. Chemical methods of measuring pH involve either the use of pH measuring electrodes or indicators whose colors are dependent on pH.

3.12.3.2. A pH meter measures the difference in potential between a pH insensitive reference electrode and an electrode whose potential is sensitive to pH.

3.12.3.3. Colored indicators are normally used in the form of pH papers.

3.12.3.4. The paper is wetted with the solution being measured and the resulting color is compared with color standards to determine the pH.

3.12.3.5. When chemical meters or indicators are used to measure the pH of soil the following procedure is used. A small amount of soil (one or two

tablespoons) is placed in a clean container. If the sample has a moisture content under 20%, a very small amount of distilled water is added. After stirring, the mixture is allowed to settle. The pH of the liquid is measured.

**3.13. Calibration of IR Drop Test Span.** The IR drop test span is a type of CP test station which is vital for determination of the direction and magnitude of DC current flowing through a pipeline.

3.13.1. In protected pipelines, this information can be used to verify current distribution and look for stray or interference current and the area of influence of installed rectifiers.

3.13.2. In unprotected pipelines, this information can be used to find anodic areas and discharge or pickup areas of stray or interference currents.

3.13.3. This method uses the metallic pipeline or cable as a shunt which is then calibrated and used to measure a Millivolt "IR Drop", from which the current can be calculated.

3.13.3.1. A known amount of DC current is applied to the pipeline. The voltage drop across the length is measured.

3.13.3.2. The resistance can be calculated if the length and wall thickness of the pipeline test span is accurately known. See table 3.4 to estimate the resistance of the test span.

3.13.3.3. The line current can be calculated using ohms law,  $E = I * R$ , where E is the measured voltage drop, R is the Resistance of the test span.

3.13.4. One other method for determining the direction and magnitude of DC current flowing through a pipeline is to use a clamp-on milliammeter. This method requires a very specialized piece of equipment, sized to the pipeline, and an excavation or access to the pipeline, for placement of the probe around the pipeline.

3.13.5. Do not use an ohmmeter to measure the resistance of the pipeline or cable.

3.13.5.1. The current flowing on pipeline or cable will flow through the meter and damage could result.

3.13.5.2. If that current does not damage the meter, the measurement would not indicate a true resistance value. The voltage would be interpreted by the meter as coming from the internal battery instead of the external electrical circuit being measured.

3.13.6. The preferred method is to measure the actual resistance of the pipe using test current. This method:

3.13.6.1. Does not require knowledge of the pipeline size.

3.13.6.2. Does not require knowledge of the pipeline wall thickness.

3.13.6.3. Is not affected by variations in the metal due to composition or corrosion.

3.13.6.4. Is not affected by variations of resistance due to temperature.

3.13.6.5. Is not affected by inaccurate lengths of the test span.

3.13.6.6. The amount of test current required depends on the diameter of the pipeline and the distance of the test span.

3.13.6.7. The larger the pipeline, the larger the amount of current required.

3.13.6.8. The shorter the distance of the test span, the larger the amount of current required.

3.13.7. Calibration of an IR Drop test span consists of two measurement circuits.

3.13.7.1. The outside circuit consists of:

3.13.7.1.1. An Ammeter to measure the current.

3.13.7.1.2. A DC power supply.

3.13.7.1.3. An on/off switch.

3.13.7.1.4. Some means of adjustment.

3.13.7.1.5. A portable rectifier may be used as the current source, switch and the means of adjustment.

3.13.7.2. The inside circuit consists of a Millivolt Meter, connected across the test span.

3.13.8. Pipelines and cables inherently will have current flowing at all times. Therefore, a change in voltage drop measurement is compared to the amount of test current applied.

3.13.9. Following all polarities, connect all circuit components. Polarity is important for correct determination of the direction of the current flow in the pipeline or cable during subsequent test procedures.

3.13.10. With Outside Circuit switch off, record the mV measurement of the inside circuit. Starting at a low current level:

3.13.10.1. Turn the outside circuit switch on.

3.13.10.2. Adjust current up to the desired test current.

3.13.10.3. Record the measurement of the test current.

3.13.11. With Outside Circuit remaining on, record the mV measurement of the inside circuit.

3.13.12. Apply this data to the following formulas:

$$\text{Resistance} = \frac{\text{Voltage On} - \text{Voltage Off}^*}{\text{Test Current applied}}$$

$$\text{Factor} = \frac{\text{Test Current applied}}{\text{Voltage Change}^*}$$

3.13.13. Voltage Change must consider polarity.

3.13.13.1. For example, 4.1 mV on, minus 1.3 mV off, is a voltage change of 2.8 mV.

3.13.13.2. Whereas, 4.1 mV on, minus -1.3 mV off, is a voltage change of 5.4 mV.

3.13.13.3. (+ mV ON - -mV OFF = +mV ON + mV OFF = Voltage Change).

3.13.14. Record the resistance of the test span and the calibration factor established. If the temperature of the pipeline or cable remains constant, this calibration factor can be stenciled on the IR Drop Test Station and used for future measurements. If doubt exists or temperatures change, perform the calibration steps each time measurements are taken.

3.13.15. Direction of current flow is determined by the polarity of the mV reading taken on the inside circuit, with meter positive on left, negative on right. A positive IR Drop indicates current flow from left to right. A negative IR Drop would indicate current flow from right to left.

3.13.16. The resistance of the pipeline can be calculated if the distance of the test span is known and the size of the pipeline is accurately known. Resistance joints or insulators cannot be present on the pipeline in the test span. Variations in temperature will adversely affect the accuracy of these calculations.

3.13.17. The mV IR Drop is measured by using a Voltmeter on the mV scale. Following all polarities, connect the meter to the inside circuit and record the measurement. Polarity is important for correct determination of the direction of the current flow in the pipeline or cable during subsequent test procedures.

3.13.18. The resistance is estimated using table 3.4.

**Table 3.4. Estimated Resistance of Steel Pipelines.**

Nominal Size in Inches	Outside Diameter	Wall Thickness	Weight per Foot in Pounds	Resistance per ft in Microhms
2	2.375	0.154	3.65	79.2
4	4.5	0.237	10.8	26.8
6	6.625	0.28	19	15.2
8	8.625	0.322	28.6	10.1
10	10.75	0.365	40.5	7.13
12	12.75	0.375	49.6	5.82
14	14	0.375	54.6	5.29
16	16	0.375	62.6	4.61
18	18	0.375	70.6	4.09
20	20	0.375	78.6	3.68
22	22	0.375	86.6	3.34
24	24	0.375	94.6	3.06
26	26	0.375	102.6	2.82
28	28	0.375	110.6	2.62
30	30	0.375	118.7	2.44
32	32	0.375	126.6	2.28
34	34	0.375	134.6	2.15
36	36	0.375	142.6	2.03

3.13.18.1. The resistance is given in millionths of an ohm (.000001 ohms) per linear foot of pipeline.

3.13.18.2. This resistance value must be multiplied by the number of feet in the test span (distance in feet of the pipeline between the actual connection points of the test station leads to the pipeline).

3.13.19. This data is then applied to the following formula:

$$\text{Current} = \frac{\text{mV IR Drop}}{\text{Resistance}}$$

3.13.20. The direction of the current flow is determined from the polarity of the mV IR Drop reading measured. For example, a positive IR Drop indicates current flow from right to left, while a negative IR Drop would indicate current flow from left to right.

3.13.21. The Multi-Combination meter has the capability of measuring current by the "Null Ammeter Method". This meter can safely measure line currents under 2 amps. Do not use this method in areas which has over 2 amps of line current. Stray current variations or other fluctuations in the measurement may make keeping the meter nulled to obtain an accurate and reliable measurement too difficult. This method does not require any information on the length of the test span, diameter of the structure, or the type of metal being tested.

**3.14. Interference Testing Procedures.** When current flows through an electrolyte, it follows the path of least electrical resistance. If a metal structure is immersed in the current carrying electrolyte, it is likely to present a low resistance path for the flow of current. At the point where electrons enter the structure from the electrolyte corrosion will be accelerated. Where electrons leave the structure, corrosion will be reduced.

3.14.1. This phenomenon is called Cathodic Interference. Cathodic interference is commonly encountered on buried structures and can be detected by electrical measurements and can be controlled.

3.14.2. CP sometimes causes undesirable effects on structures not connected to the protection system. This occurs because some current is picked up by these "foreign" structures at one point, and in attempting to return to the source and complete the circuit, is discharged at another point.

3.14.3. Corrosion occurs at the current discharge point. Current can cause corrosion damage by passing between two structures or across high-resistance joints in the same structure.

3.14.4. Sources of Interference Currents may be constant or fluctuating. Constant current sources have essentially constant direct current output, such as CP rectifiers and thermoelectric generators.

3.14.5. Fluctuating current sources have a fluctuating direct current output such as direct current electrified railway systems, coal mine haulage systems and pumps, welding machines, direct current power systems, and telluric currents.

3.14.6. See MIL HDBK 1136, section 2.2.4 for explanations and sources of interference current.

3.14.7. Mitigation can usually be accomplished by installing an electrical bond between the unprotected structure (at the location of maximum discharge) and the protected structure.

3.14.8. Other mitigation methods include breaking the continuity of the foreign pipeline, coating the foreign pipeline pickup area, coating the protected pipeline in the discharge area of the foreign pipeline, and use of galvanic anodes to apply current to the discharge area of the foreign pipeline (and an alternate current discharge point).



3.14.9. See section MIL HDBK 1136, section 5.6 for information on Interference Corrosion Control.

3.14.10. Interference from CP rectifiers:

3.14.10.1. CPs systems are a major source of stray current on other metallic structures.

3.14.10.2. Structures not electrically connected to the protected structures are considered to be "foreign" structures.

3.14.10.3. A foreign structure may provide an alternate path for the current flowing from the impressed current anodes to a protected structure.

3.14.10.4. If this path is of sufficiently low resistance, significant current flow will occur.

3.14.10.5. Since there is no metallic return path, the current will discharge from the surface of the foreign structure to the electrolyte in order to return to its source, resulting in severe corrosion.

3.14.10.6. Testing requires cooperation by the owners of the structures involved.

3.14.10.6.1. Such cooperation is best effected by a corrosion coordinating committee; all companies operating underground or underwater structures, and particularly those under CP, should be members of such a committee.

3.14.10.6.2. A list of most existing committees may be obtained from the National Association of Corrosion Engineers, P.O. Box 218340 Houston, TX, 77218-8340.

3.14.10.7. Interference testing is usually performed when new CP systems are first installed but is sometimes detected through routine field measurements.

3.14.10.8. Good record keeping is very useful in preventing cathodic interference problems as any system changes, particularly additions of new buried structures, can be more easily determined when proper records are kept.

3.14.10.9. Interference tests must be made on all structures adjacent to a CP system to determine effects and to allow design of mitigation measures. Cathodic interference can be detected by measuring structure-to-soil potentials, potential gradients and current flow (IR drop) with CP current or resistance bonds on and/or cycled on and off. Structure-to-soil potentials give indications of interference only when measured in an area of current discharge or pick-up on the foreign structure.

3.14.10.10. Abnormal or unusual current distribution on a protected structure indicates possible interference on a foreign structure.

3.14.10.11. Current flow (IR drop) readings show the relationship between pick-up and discharge areas on a foreign structure.

3.14.10.12. A CP rectifier output contains a waveform, which results in a pulsating DC signal.

3.14.10.13. Presence of this pulsating DC on foreign structures indicates interference from a rectifier.

3.14.10.14. When conducting current requirement tests or initially energizing impressed current CP systems, all companies owning underground structures in the area should be notified and coordination tests made with those interested.

3.14.10.15. Current drainage requirements for each structure, from tests at various anode locations, can be determined.

3.14.11. The best method to locate interference is to perform a pipe-to-soil potential survey of the foreign pipeline with the source of the interference cycled on and off at specific intervals.

3.14.11.1. The algebraic difference between the "on" and "off" reading (potential shift) gives the interference effect on the foreign structure.

3.14.11.2. The location showing greatest pipe-to-soil potential change in the positive ("unprotected") direction is called the "critical" or "control" point.

3.14.11.3. This is often at the point where protected and unprotected pipelines cross. The areas showing pipe-to-soil potential change in the negative ("protected") direction are called "pickup" areas.

3.14.11.4. Presence of a pickup area on a foreign structure indicates that interference is present, and a discharge area exists somewhere on that structure.

3.14.11.5. If metallic continuity exists between the foreign structure and the negative terminal of the rectifier, this is not interference, it is protection, and no discharge area exists (and therefore, by definition is not a foreign structure).

3.14.12. If the source of the cathodic interference is not known, it can be detected by measuring structure-to-soil potentials with CP current on and potential gradients.

3.14.13. Structure-to-soil potentials give indications of interference only when measured in an area of current discharge or pick-up on the foreign structure. Potential gradients are measured by the cell-to-cell test procedures in paragraph 3.5.

3.14.14. Taking these measurements along the foreign pipeline may locate the discharge point and pickup areas.

3.14.14.1. The polarity must be ascertained to determine the direction of current flow and magnitude. Current will flow in the direction of the discharge point. The magnitude will increase as you near the discharge point.

3.14.14.2. The direction will reverse upon passing a discharge point. The reversal with the highest magnitude is the "control" or "critical" point. The

discharge point is normally near the structure, which is causing the interference.

3.14.14.3. The pickup area is normally near the anode system, which is causing the interference. Locating the pickup area is important in locating the source of the interference, since it shows the direction that the current is coming from.

3.14.15. Measurement of the current flow (IR drop) on a foreign pipeline can be accomplished if other methods are inconclusive.

3.14.15.1. Current flow (IR drop) readings show the relationship between pick-up and discharge areas on a foreign structure.

3.14.15.2. By measuring the current flow on a foreign structure, the direction of the discharge point and pickup areas can be determined.

3.14.15.3. Magnitude indicates seriousness, and increases as the distance to the discharge point decreases.

3.14.15.4. These measurements can be easily accomplished if IR drop test stations already exist or if the pipeline is accessible (comes aboveground or passes through pits).

3.14.15.5. Current is measured at an IR drop test station by the procedures detailed in paragraph 3.13.

3.14.15.6. Current is measured where access to the pipeline is possible using a clamp-on milliammeter (such as the Swain CP AmpClip). The correct size clamp must be used for the pipeline under test. Note: Typical clamp-on meters do not work in this application, it must be capable of measuring DC amps, with a range capable of accurate measurement of under 30 milliamps.

3.14.16. Abnormal or unusual current distribution on a protected structure indicates possible interference on a foreign structure. Normally the potential of a protected structure decreases slightly as distance from the anodes

increases. At defects in coatings the potential of a protected structure decreases. An increase in potential normally indicates current pickup. If the potential of a protected pipeline increases when crossing a foreign pipeline, interference is likely on that structure. Potential survey of that structure, while interrupting the source of current will indicate the presence and magnitude of that interference.

3.14.17. A CP rectifier output contains a waveform, which results in a pulsating DC signal.

3.14.17.1. This signal can be located using a pipe locator capable of following a 120 cycles per second (cps) signal (such as the Pipe Horn, Model 200 FDAC, in rectifier mode).

3.14.17.2. Presence of this signal indicates presence of interference on the foreign structure.

3.14.17.3. Combining this method with a current interrupter on suspected sources of the interference will expeditiously locate the source of the interference.

3.14.17.4. Signal strength can sometimes be used to indicate the direction of the discharge and pickup areas.

3.14.17.5. Normally signal strength will increase in the direction of the discharge point. This may not occur with multiple discharge areas.

3.14.18. Another method of interference testing is to use an experimental drainage bond between structures.

3.14.18.1. Proper drainage can be determined by trial-and-error, using a variable resistor to alter drainage current.

3.14.18.2. Required drainage current can also be computed from test data.

3.14.18.3. When the same owner maintains the protected structure and the foreign structure, this method may be easily used.

3.14.18.4. The source of interference is cycled on and off at specific intervals and the bond resistance is adjusted until no potential shift occurs on the foreign structure.

3.14.18.5. When site conditions warrant, the bond may be sized to apply partial or full protection to the foreign structure.

3.14.18.6. If the foreign structure is small or well coated, and the protected structure is poorly coated, this option may be taken when sufficient CP current is still available to maintain protection on the protected structure.

3.14.19. Interference from variable (fluctuating) sources. While interference testing determines effects of steady stray currents, another type of stray current survey analyzes fluctuating stray currents. Fluctuating or periodic changes in structure-to-electrolyte voltage values and unusual or fluctuating currents are indicative of stray currents.

3.14.19.1. Stray currents may affect structures just as CP does. Structures may be protected or damaged by stray DC currents, depending on whether current is flowing to or from the structure.

3.14.19.2. Such analysis is specialized and requires study to master all techniques.

3.14.19.3. The basic principles are the same as in the previous section (see above). The difference is that the stray DC current is not present at the same location all the time. DC current pick-up and discharge areas are constantly changing.

3.14.19.4. The use of data loggers or recording devices at many points on the foreign structure, simultaneously, will indicate the same information as above.

3.14.19.5. Locating the discharge point(s) and pickup areas are still crucial.

3.14.19.6. In this case, determining the time of the interference is also crucial.

3.14.20. All the basic measurements can be used in studying fluctuating stray currents. Perhaps the most informative are measurements similar to those used in interference testing; structure-to-electrolyte potentials and IR drops along structure or electrolyte. Methods of analysis, however, are different and specialized equipment is used. The major concern in performing a stray current survey is to find out the degree of damage and determine the source of the stray DC current.

3.14.21. Measurement of the foreign pipeline potentials is commonly used to determine the pickup and discharge areas.

3.14.21.1. Using data loggers or recording devices, many locations on the foreign structure are monitored simultaneously.

3.14.21.2. This data is then charted to analyze for the presence of interference.

3.14.21.3. When the exact moment of interference is determined, all potential readings taken at that instant are used to determine the discharge and pickup points.

3.14.21.4. Data taken is used to locate areas for taking additional data.

3.14.21.5. Once gathered, this data is used exactly like the data for cathodic interference detailed previously.

3.14.21.6. Abnormal potentials on other structures may also be used for further analysis.

3.14.21.7. Once the pickup area and time is determined, the source of the current may be located (see MIL HDBK 1136, section 2.2.4 for sources of fluctuating stray currents).

3.14.22. Another method of finding these points is through current measurements.

3.14.22.1. In order to determine the pick-up and discharge points in fluctuating stray current areas, data from several test points are plotted over a period of time.

3.14.22.2. Current values on the several locations on the foreign structure (recorded from IR drop test spans or a clamp-on milliammeter) are plotted over a period of time.

3.14.22.3. The current must be measured at several points simultaneously, sufficient readings being made to cover the range of variation of the current (usually at least 24 hours) using recording voltmeters and or data loggers.

3.14.22.4. By analyzing the current direction and magnitude at the time the interference is occurring, the relationship and direction of the pickup areas and discharge areas can be determined.

3.14.22.5. Once the time of interference is known, the area of pickup can be searched for possible sources of the current pickup (see MIL HDBK 1136, section 2.2.4 for sources of fluctuating stray currents).

3.14.22.6. Outside of the necessity of taking simultaneous readings due to the fluctuating current, this method is the same as conventional line current measurement.

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