Testing Cathodic-Protection Systems

by Marcel Moreau

Testing cathodically protected structures is rarely a "cookbook" type of procedure. A clear understanding of cathodic-protection principles is a prerequisite for the correct execution of the monitoring procedure and a reasonable interpretation of the monitoring results. Having said that, I hereby offer my recipe for monitoring the status of a cathodically protected UST system. My goal is not to turn any casual reader into a cathodic-protection tester, but to provide some guidance for those who need a refresher. An understanding of how the monitoring procedure should be carried out may also help regulators and storage system owners understand what's what when they are reviewing cathodic-protection monitoring reports.

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TESTING GALVANIC CATHODIC-PROTECTION SYSTEMS

Equipment Needed:

- A copper/copper sulfate reference electrode (also A voltmeter with at least 10 megohm (million ohms) input impedance. Most voltmeters with a digital display will meet this requirement. Although a model from a consumer electronics store will give accurate readings, a voltmeter specifically intended for cathodic-protection monitoring will likely be more durable in the field environment.
- A copper/copper sulfate reference electrode (also known as a "half-cell" or "reference cell"). Typical reference electrodes are about 1 inch in diameter and 6 inches in length. They may have either a flat or a cone-shaped, porous ceramic tip at one end that is covered with a plastic cap. The cap must be removed when cathodic-protection measurements are conducted, but it should be kept in place on the reference electrode whenever it is not in use to minimize evaporation of the copper sulfate solution inside the electrode.

  Maintain the reference electrode as follows:
  - Keep the reference electrode about 3/4 full with distilled water.
  - Be sure that undissolved copper sulfate crystals are always visible inside the reference electrode.
  - Discard the solution inside the reference cell when it becomes cloudy. Refill the reference cell with copper sulfate crystals and distilled water. Clean the copper rod with nonmetallic sandpaper.
  - Keep the reference cell away from freezing temperatures so that the copper sulfate solution does not freeze, or use the copper sulfate anti-freeze solution provided by the half cell manufacturer.
- Two test leads (plastic coated wires with fittings on the end) that plug into the voltmeter and can be clipped onto the reference cell and the structure being monitored. Test leads can be any length; however, 2- to 3-foot lengths are typical. For field work, it is also a good idea to have a 20- to 30-foot length of wire with test clips on each end handy, in addition to the two test leads.
- A standardized form that can be used to record pertinent information concerning the facility, sketch the facility, note voltage readings, and indicate the locations where voltage measurements were made.

Testing Procedure:

1 Determine how you will obtain an electrical connection with the structure that is to be monitored. If you are monitoring an sti-P3® tank, there may be a monitoring wire (usually green in color) coming up out of the ground and attached to the submersible pump riser, the automatic tank gauge riser, or the fill pipe riser ("riser" is a generic term for a vertical pipe attached to an underground tank), or located in a special cathodic-protection test station. If no wire can be found, see the "What If...?" section that follows.

2 Determine where you will place the reference cell. The reference cell must be in contact with clean, moist soil, not with concrete or asphalt. See the "What If...?" section that follows if no clean soil is accessible. The ideal location is along the top middle of the tank. On many tanks installed after 1990 or so, this is where the automatic tank gauge riser is located and where soil is usually accessible. Other possible locations are around the submersible pump or, if the tank Is double-walled, the riser that leads to the interstitial space of the tank.

The purpose of monitoring is to ensure that the entire tank is protected. This means that the portion of the tank farthest away from the anodes must still meet the criteria for protection. Sti-P3®

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tanks of 10,000 gallons and less have anodes located on the ends; this means that the lowest voltage reading would be expected when the reference electrode is placed at the top middle of the tank. Readings taken with the reference electrode placed near the ends of the tank are usually, but not always, higher. If there is no access to soil over the top of the tank, see the "What if...?" section that follows.

It is good practice to take voltage readings with the reference electrode in as many locations as practicable to verify that the entire tank shell is protected. A minimum of three readings is usually required. Some protocols require at least two readings with the reference cell over the top of the tank and one reading with the reference cell remote from the tank. (For a discussion of the value of remote readings, see Kevin Henderson's article "Should Remote Earth Testing of Galvanic Cathodic-Protection Systems Be Required" in *LUSTline* Bulletin #48, November 2004.)

I have seen tanks where one end of the tank registered 0.95 volts, the middle registered 0.88 volts, and the other end registered 0.83 volts. This situation could result from an actual deficiency in the cathodic protection caused by significant coating damage at one end of the tank or failure to unwrap the anode at one end of the tank. This deficiency could not have been discovered if only a single reading had been made at the middle of the tank. Note, however, that this situation could also result from petroleum contamination in the soil where the reference cell is placed (e.g., around the submersible pump) or from something that acts to shield the reference cell from the tank (e.g., a metal culvert around the submersible pump).

3 Unless the soil where you intend to place the reference electrode is quite wet, you will need to add moisture. Pour a quart to a gallon of water on the location where the electrode is to be placed and allow the water to be absorbed into the soil before taking the reading.

4 Turn on the voltmeter and watch the display to be sure that it is behaving normally. Consult the meter's instructions if you don't know what it is supposed to read when you first turn it on. If your instrument has multiple functions, be sure that it is set to make low voltage DC measurements and that the test leads are plugged into the correct sockets. Connect the positive lead of the voltmeter to the wire from the structure to be monitored and the negative lead from the voltmeter to the terminal at the top of the reference electrode. Do not touch any metal portions of the test leads when making a reading.

The display on the meter should be steady. Fluctuations of 0.01 volt are okay, but fluctuations greater than this may indicate a bad connection. There should be a negative sign in front of the reading, and the reading should be more negative (greater) than -0.85 volts (which is the same as -850 millivolts). Don't let the negative sign confuse you (-0.90 volts is greater than -0.85 volts [this is what you want]; -0.80 volts is less than -0.85 volts [this is what you don't want]). The table on page 3 "Interpreting What Your Voltmeter Is Telling You"should help you interpret your readings.

5 No job is done until the paperwork is completed. While you should document the cathodic-protection monitoring with the usual site information (e.g., facility name, address), you should also make a quick sketch of the layout of the facility and indicate the reference electrode location(s) and the corresponding voltage readings. Duplicating the reference cell locations over time is key to obtaining meaningful cathodic-protection data.

What If...?

What if there is no monitoring wire for the tank?

You need an electrical contact with the tank. If the tank is an sti-P3® tank, all of the risers attached to the top of the tank are electrically isolated from the tank shell and cannot be used to obtain readings of the tank itself. To obtain a reading in this situation, make contact with the bottom of the tank through the fill pipe.

A "quick and dirty" way to do this is to fasten a length of wire (20-feet long or so) to a brass bolt and then fasten the bolt with a stainless steel hose clamp to the end of a dipstick so that the head of the bolt extends slightly beyond the end of the stick. Clip the end of the wire that is not attached to the bolt to the positive test lead from the voltmeter.

Insert the bolt end of the stick into the fill pipe and press firmly against the bottom of the tank. There may be sludge and scale on the tank bottom which will require firm pressure and a little twisting motion on the stick to obtain good electrical contact. Good contact is indicated by a steady reading on the digital display of the voltmeter.

Be aware, some drop tubes are equipped with tank bottom protectors to prevent any damage that might occur when the dipstick repeatedly strikes the bottom of the tank. The tank bottom protector consists of a metallic plate that is attached to the bottom of the drop tube. A neoprene disc separates the bottom protector and the bottom of the tank, electrically isolating the tank bottom from the tank bottom protector.

Because the tank bottom protector is connected to the drop tube and the drop tube is connected to the fill pipe, the voltage reading obtained through the fill pipe will reflect the voltage of the fill pipe relative to the reference electrode, rather than the tank voltage. So if the dipstick method results in a reading in the unprotected range (0.4 to 0.6 volts) take a reading on the fill pipe. If the fill pipe reading and the dipstick reading are identical and a drop tube is present, remove the drop tube and check for a tank bottom protector before concluding that the tank is not adequately protected.

In some cases, if the tank is equipped with a manway at the bottom of a containment sump, it may be possible to contact the tank shell directly. Look carefully around the manway to determine how electrical isolation is being accomplished and whether any metal connected to the

INTERPRETING WHAT YOUR VOLTMETER IS TELLING YOU

READING	WHAT READING INDICATES
Greater than -1.65 volts for a structure with magnesium anodes	The maximum voltage output from a magnesium anode is -1.65 volts. If your reading is greater than this, the system could have impressed current cathodic protection rather than galvanic, or there could be stray currents in the vicinity. If it turns out this is NOT an impressed current system, have a corrosion engineer investigate as soon as possible.
Greater than -1.1 volts for a structure with zinc anodes	The maximum voltage output from a zinc anode is -1.1 volts. If your reading is greater than this, the system could have impressed current cathodic protection rather than galvanic, or there could be stray currents in the vicinity. If it turns out this is NOT an impressed current system, have a corrosion engineer investigate as soon as possible.
Greater than -0.88 volt	Structure is adequately protected.
-0.85 volt to -0.88 volt	Structure still meets the standard for corrosion protection, but there is not much of a safety cushion. Monitor the system closely to determine the rate at which the voltage is dropping and plan on adding anodes or performing other work on the system in the not too distant future.
Less than -0.85 volt	The structure does not meet the -0.85-volt standard for corrosion protection and is out of compliance with regulatory requirements. This does not mean, however, that the tank is leaking. (See "What if the tank or piping does not meet the -0.85 criterion?" in the following section.)
-0.4 volt to -0.6 volt	Expect this voltage range from steel that has no cathodic protection. This could indicate that the tank was not cathodically protected originally, or that the anodes are completely shot. Call in a corrosion engineer to investigate.
-0.3 volt to -0.4 volt	Rusty steel will sometimes register down in this range. Call in a corrosion engineer to investigate.
-0.1 volt to 0.0 volt	This type of reading is most likely to occur if you are measuring the potential of a piece of copper. Most likely the copper wire you are connected to is broken off underground. Find another way to get an electrical connection to the structure you want to monitor.
Variable readings	This could indicate stray currents, but check your meter to be sure that it is operating properly and that all test lead connections are in solid contact with shiny metal.
Wildly fluctuating readings (digital meter)	This probably indicates that one of your test lead connections is not good or that your reference cell is dry. Make sure that all your connections are solid metal to metal. Might also be indicative of extremely dry conditions in the backfill. Run water from a garden hose into the tank backfill for a couple of hours and take another reading.

tank shell, or the tank shell itself, is accessible.

What if tank is equipped with a PP4 monitoring station?

If the tank is an sti-P3® tank installed around 1993 or later, it may have a test station consisting of a plastic dome about 3 inches in diameter with five metal terminals imbedded in it that are flush with the surface of the dome. The central terminal connects to a permanently buried reference cell (you don't need your copper/copper sulfate reference electrode to test this tank), and the four terminals around the center connect to one or more tanks. Simply connect the negative voltmeter lead to the center terminal and the other lead to each of the other terminals on the test station. You should get appropriate readings on as many terminals as there are tanks buried at the facility.

What if I need to monitor piping?

Cathodically protected piping is rarely equipped with monitoring wires to facilitate cathodic-protection monitoring, but this is not a serious omission in most cases. Usually, the piping will be accessible at both the top of the tank and beneath the dispenser. There is typically also soil exposed at these locations for placing the reference electrode. If the anodes have been installed as suggested in

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the Petroleum Equipment Institute's "Recommended Practices for Installation of Underground Liquid Storage Systems" (PEI RP100), the ends of the piping will be the points in the system the furthest away from the anodes and are good places to locate the reference electrode. Be sure that the point of contact between the piping and the voltmeter test lead is clean shiny metal to ensure a good reading.

What if there is no soil along the tank top in which to place the reference electrode?

It is possible to get voltage readings by placing the reference electrode on damp concrete or asphalt, but these readings are NOT accurate or reliable. In my experience, readings taken with the reference electrode on concrete will always yield a reading that is higher than a properly conducted voltage reading. Readings through asphalt are unreliable because the voltage is determined by the location of cracks in the asphalt and not the actual placement of the reference cell. In my view, the solution is to drill a hole through the concrete or asphalt to allow direct contact between the reference cell and the soil in close proximity to the tank top.

What if the soil is "dry"?

I often hear that storage systems fail to meet cathodic-protection criteria because the tank environment is too dry. While this may occasionally be true in parts of the desert southwest, it is not a likely occurrence in most other parts of the United States. If excessively dry conditions are suspected, run a garden hose to the tank top and pour a large amount of water into the tank backfill.

What if the soil where I need to place my reference electrode is contaminated with petroleum?

Don't take a reading in soil that is saturated with petroleum. Petroleum is not an electrolyte; the reference electrode must contact an electrolyte (e.g., water) for the reading to be accurate. A slight petroleum odor is acceptable for cathodic monitoring purposes, but soil saturated with petroleum will seriously affect readings.

What if the soil is frozen?

Traditional wisdom indicates that cathodic-protection monitoring cannot be conducted in frozen soils because ice is not an electrolyte. Experience in Maine indicates, however, that monitoring can be conducted in frozen soils if water is used to dampen the soil where the reference electrode is placed. The better practice, however, is to plan your cathodic-protection monitoring for the warmer months when the frost is out of the ground.

What if the tank or piping does not meet the -0.85 criterion?

The most common reason for failure to meet the -0.85 criterion for galvanic cathodic protection is failure to electrically isolate the cathodically-protected structure from other buried metallic or electrical components. The best method for identifying such components is to measure the voltage of all accessible metal (e.g., piping, electrical conduit, utility piping, leak detection probes). This is done by measuring the tank voltage as described in steps 1 through 5 above and then connecting the negative lead of the voltmeter to all accessible metallic structures without moving the reference cell. (This is where that 20- to 30-foot length of wire from the "equipment needed" section comes in handy.) A reading of within a few millivolts of the tank reading indicates that the two structures are electrically connected. The exact place where the two structures are in contact must be located and the connection broken for the cathodic protection to work.

Inadequately isolated tank-anchoring hardware, although a likely source of electrical isolation problems, usually cannot be evaluated using this technique, because the voltmeter connection cannot be made unless the top of the tank is excavated.

Another possible reason for failure to achieve -0.85 volt is excessively dry soil. Refer to the "What if the soil is dry?" section above.

If the tank is isolated and the backfill is damp, but -0.85-volt reading still cannot be measured, research the installation procedures to see if you can discover any clues. Then call the Steel Tank Institute, the tank manufacturer, or a corrosion engineer for help.

TESTING IMPRESSED CURRENT CATHODIC-PROTECTION SYSTEMS

Equipment Needed:

The equipment list for monitoring impressed current cathodic-protection systems is the same as for galvanic systems.

Testing Procedure:

1 Making an electrical connection to a structure with impressed current cathodic protection is relatively easy; none of the components should be electrically isolated from one another. The fill pipe or any other accessible tank riser is usually a good place to make a connection to the tank.

One case where this may not be true is when impressed current cathodic protection has been added to a sti-P3® tank. In this case, use the continuity test described under the galvanic cathodic-protection question "What if the tank or piping does not meet the -0.85-volt criterion?" to check to be sure that all metallic components of the system are continuous. Use the dipstick method described under the question "What if there is no monitoring wire for the tank?" to check the voltage of the tank shell.

2 The guidelines for placement of the reference cell are basically the same as for galvanic systems. The reference cell should be close to the structure being monitored and as far away from the anode locations as possible. Anode locations can often be inferred from saw cuts and small areas of patched asphalt or concrete. Anode locations should also be indicated on the cathodic-protection design documents.

3 The soil where the reference electrode is placed should be wet as for galvanic systems.

4 Test lead connections and voltmeter settings are also the same for impressed current systems as for galvanic systems.

5 The 0.85-volt criterion most commonly utilized for galvanic cathodic-protection systems is not appropriate for impressed current systems. There are many differing opinions among corrosion engineers as to the best technique for monitoring the effectiveness of impressed current systems. The 100 millivolt (0.1 volt) polarization decay criterion that is described here is included in the National Association of Corrosion Engineers' document RP-0285-95, and is accepted as valid by most knowledgeable corrosion engineers.

The set-up of the monitoring equipment (reference electrode, voltmeter, and test leads) is the same as for galvanic monitoring. What is monitored, however, is the change in voltage of the structure that occurs after the power to the rectifier is shut-off. This procedure is often carried out using two people to execute it properly: one person to switch off the rectifier, and the other to monitor the change in voltage of the underground storage system. There are also automatic switching devices that can be used to repeatedly cycle the rectifier from on to off so the measurement can be made by one person.

When the power to the rectifier is interrupted, there will be an immediate drop in the voltage reading at the tank, followed by a continuing slow decline in the voltage. The person monitoring the voltmeter must note the voltage reading immediately after the power to the rectifier is interrupted. (If the meter is digital, the numbers will change rapidly. The reading you want is the second number that appears on the meter's display.) The voltage is then monitored for several minutes (possibly much longer in stubborn cases) with the rectifier turned off. The criterion for cathodic protection is a voltage shift of at least 0.10 volt from the initial reading after the power to the rectifier is cut off. For example, a system might have a voltage of -1.1 volts with the power to the rectifier turned on. Immediately after shutting off the power to the rectifier, the voltage might drop to -0.83 volt. The voltage must then drop below -0.73 volt (0.83 - 0.10 = 0.73) to meet the criterion for effective cathodic protection.

Another way to determine if this criterion for cathodic protection has been met depends on whether the original voltage of the tank (i.e., before any cathodic protection was applied) is known. If the voltage reading immediately after the rectifier is turned off is at least 100 millivolts more negative than the original unprotected voltage, then the 100 millivolt criterion has been met. ■

Do not forget to restore power to the rectifier before you leave the site!