

Engineering Encyclopedia

Saudi Aramco DeskTop Standards

Monitoring Cathodic Protection Systems

Note: The source of the technical material in this volume is the Professional Engineering Development Program (PEDP) of Engineering Services.

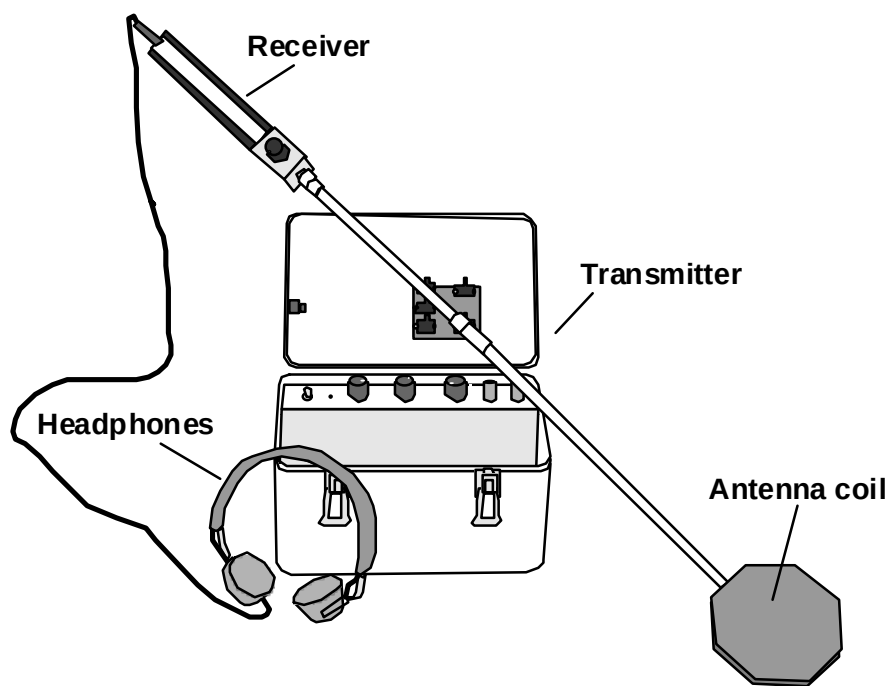
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LOCATING BURIED PIPELINES

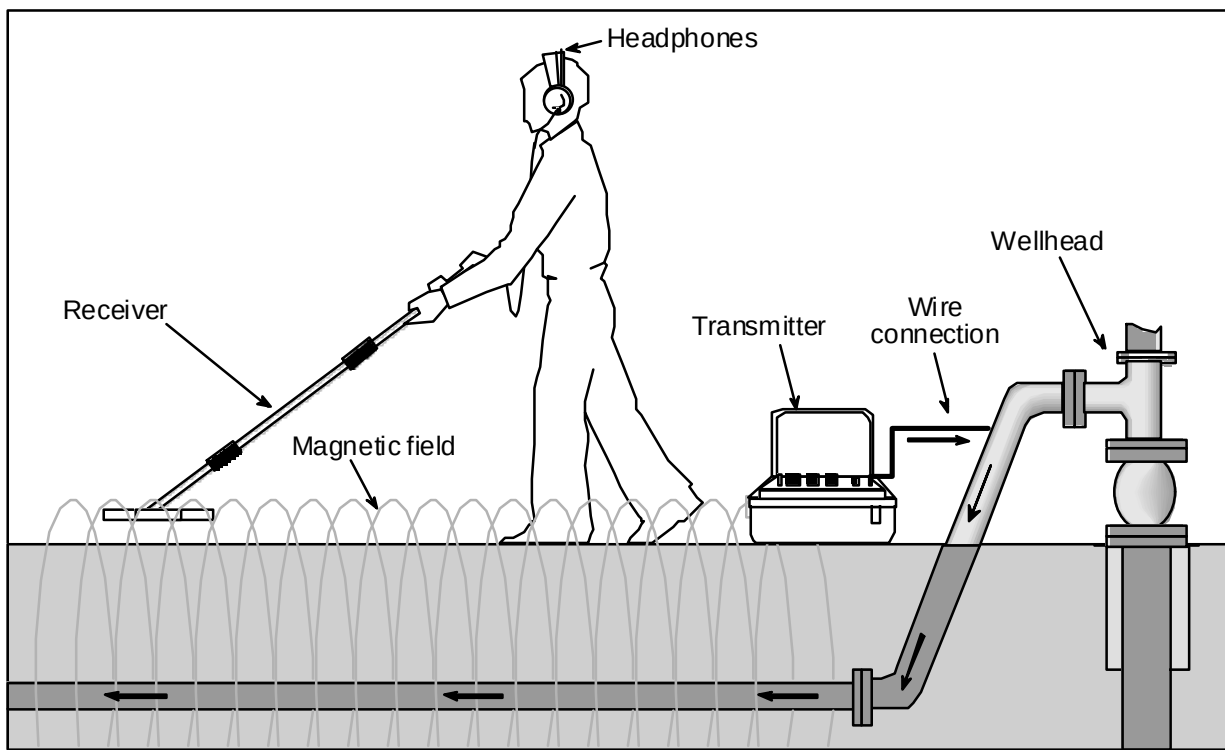
During a cathodic protection survey, it is sometimes necessary to locate a buried pipeline and other structures that cross the pipeline. The pipe locator makes this task easier and quicker. There are basically two types of pipe locators: conductive and inductive. Both types of pipeline locators contain an alternating current transmitter that impresses an ac signal on the pipe to be located. The transmitter signal creates a magnetic field around the pipe. The pipe is located through the use of a receiver that detects the magnetic field. In conductive type pipe locators, the ac signal is conducted to the pipe by a direct wire connection. In the inductive type pipe locator, the ac signal is induced in the pipe by an induction coil. Since Saudi Aramco uses conductive pipe and cable locators, we will limit our discussion to this type.

A conductive pipe locator is shown in Figure 1. The transmitter converts direct current from a 12 V dry cell battery to alternating current. The receiver is housed in a square phenolic tube that forms the handle for the flat antenna coil. The receiver contains input circuitry, an on-off volume control, an amplifier, batteries, and an output jack. The antenna coil is inserted into a jack at the volume control end of the receiver. The antenna coil is moulded in an epoxy compound and mounted on a hinged joint rod. A bubble level is attached to the antenna coil to indicate both horizontal and 45 degree inclinations. A set of headphones is plugged into the output jack at the opposite end of the receiver.



Conductive Type Pipe Locator
Figure 1

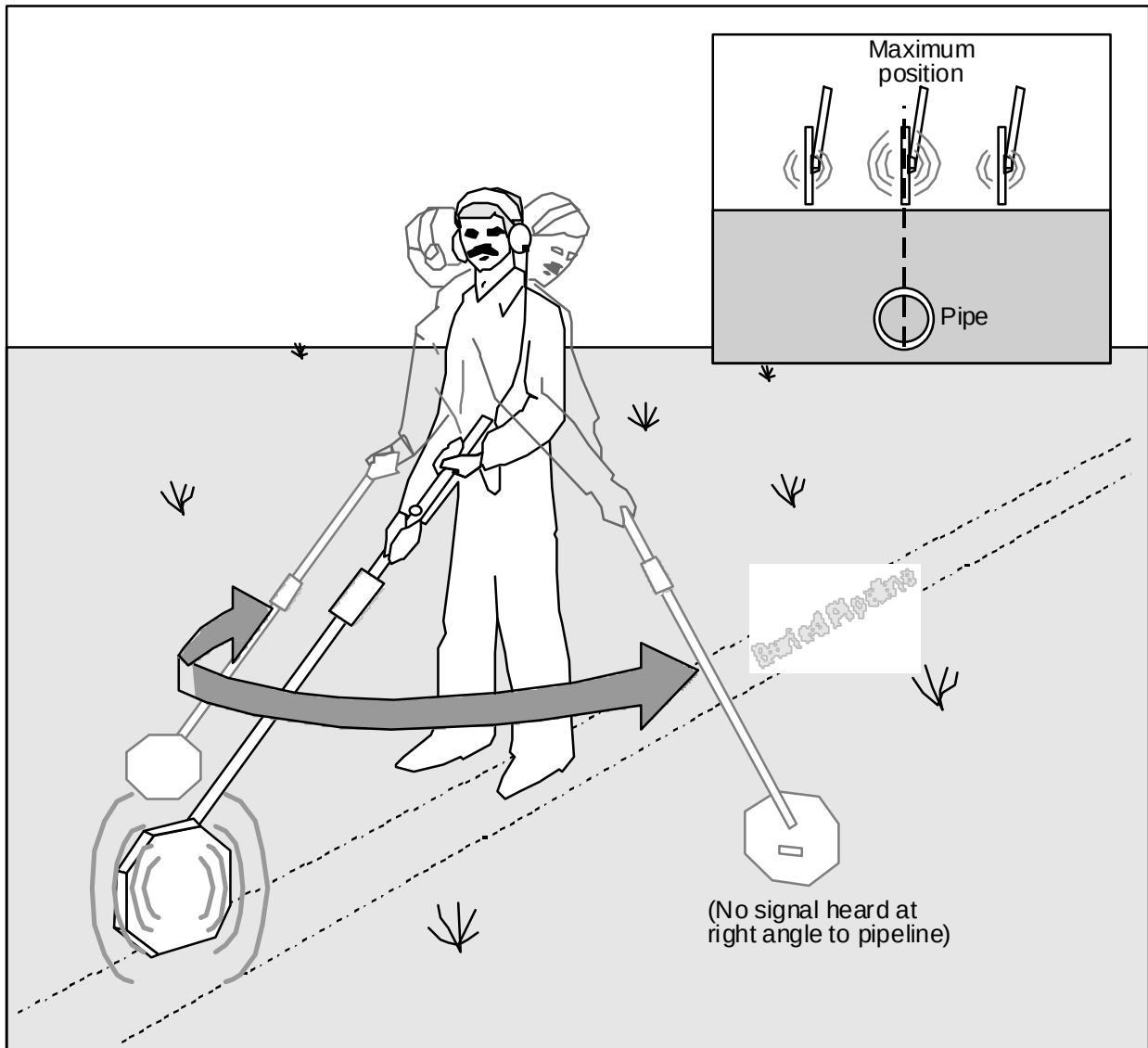
The transmitter contains a circuit that generates a distinctive electrical signal current. Alternating current is caused to flow onto the pipeline through a direct wire connection as shown in Figure 2. This current creates a magnetic field around the pipe. The magnetic field continuously expands and collapses at a frequency proportional to the frequency of the transmitted signal. When the antenna coil is placed in the magnetic field, an electric current is induced in the receiver. The current is amplified and produced as an audible tone in the headphones. The pipe locator contains a device that interrupts the transmitter output to give a pulsing tone. The pulsing tone allows the operator to distinguish between the pipe locator tone and tones that are caused by ac power line interference.



Operation of a Conductive Type Pipe Locator

Figure 2

The relative loudness of the signal, together with the position of the antenna coil, enable the operator to precisely determine the path and depth of a pipeline or cable. When the receiver coil is vertical and parallel to the pipeline, the voltage induced in it is at a maximum and the tone is the loudest (Figure 3). This is called the maximum position. The signal fades as the coil is moved from the maximum position. When the coil is at a right angle to the pipeline, no signal will be heard.

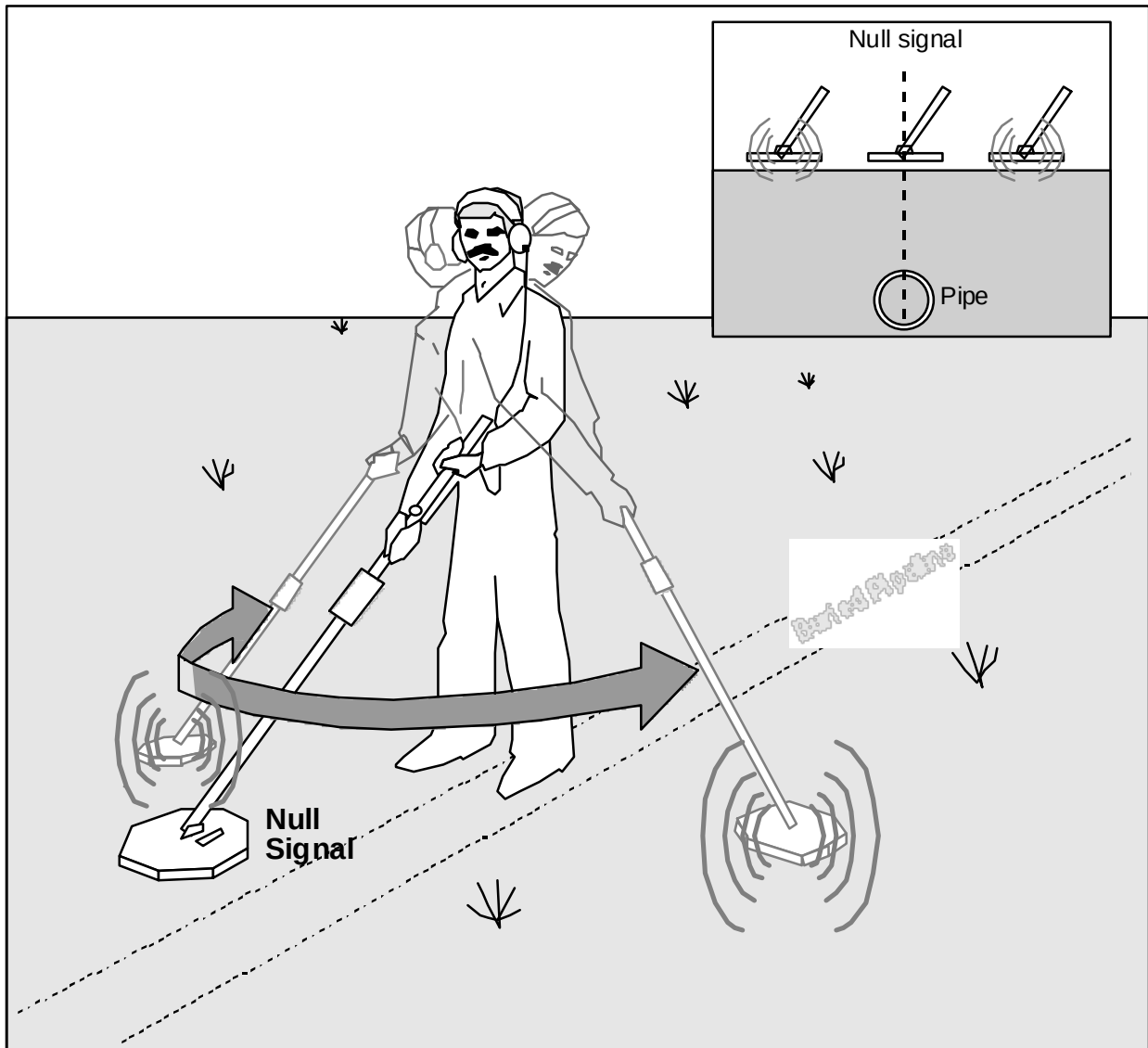


Pipe Locator in Vertical Position

Figure 3

For more accurate pipeline location, the receiver is placed in a horizontal position as shown in Figure 4. When the horizontal coil is placed directly over the pipeline, equal and opposite voltages are induced in the two sides of the coil. These equal and opposite voltages cause a null signal in the headphones. If the coil is moved a short distance from directly over the pipeline, an imbalance is created, and a tone is heard in the headphones.

Work Aid 1 contains a procedure to use a pipe locator.



Pipe Locator in Horizontal Position

Figure 4

MEASURING STRUCTURE-TO-ELECTROLYTE POTENTIAL

Cost-effective corrosion control of onshore and offshore structures requires that an adequate amount of cathodic protection current is applied without over-protecting the structure. The question is, "How do we know when an adequate level of cathodic protection has been reached?"

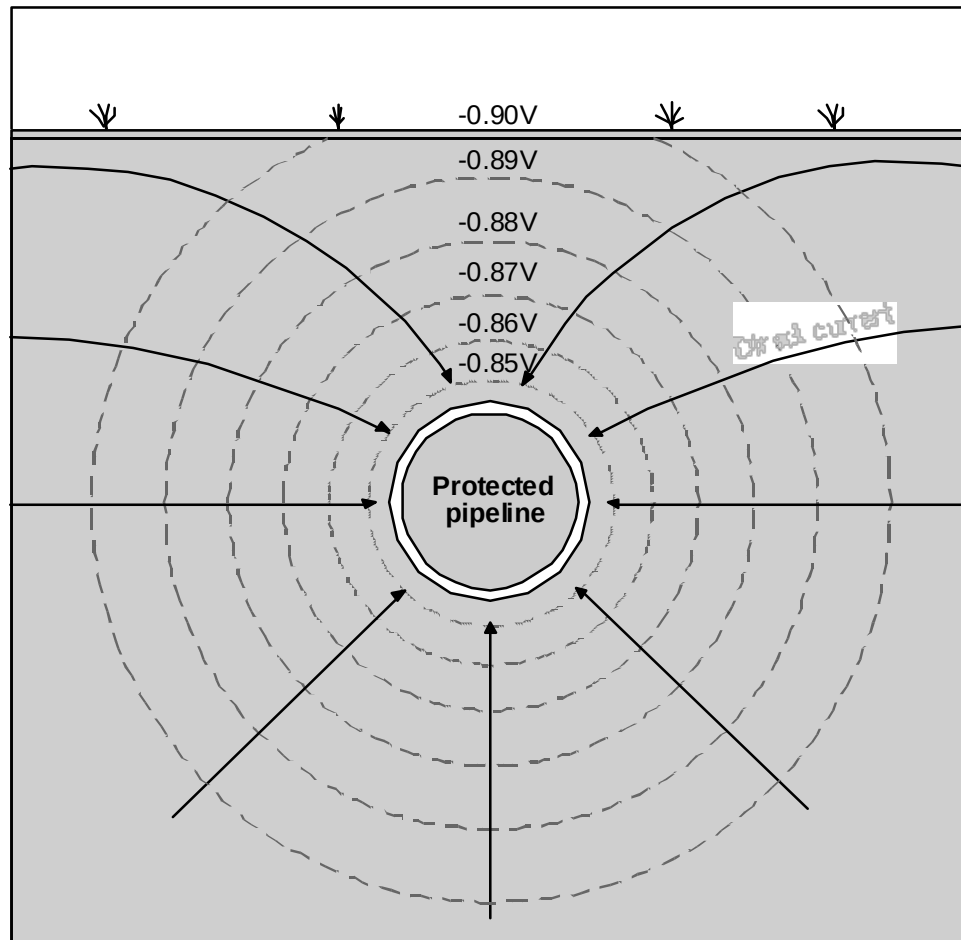
The most widely used criterion for cathodic protection is based on the potential difference between the structure and its environment. Figure 5 shows Saudi Aramco's potential requirements for various structures.

Structure	Required Potential
Current On	
Buried cross-country pipeline	-1.20 volts or more negative versus CuSO_4
Buried plant piping	-0.85 volt or more negative versus CuSO_4 electrode +0.25 volt or less positive versus Zn
Tank bottom external	-1.00 volt or more negative versus CuSO_4 at periphery -0.85 volt or more negative versus permanent CuSO_4 +0.20 volt or less positive versus permanent Zn -0.35 volt change in structure potential vs CuSO_4
Tank interior	-0.90 volt or more negative versus AgCl electrode +0.15 volt or less positive versus Zn
Marine structures	-0.90 volt or more negative versus AgCl electrode
Current Off	
Well casings	-1.00 volt or more negative versus CuSO_4 (G.I. 428.003)

Saudi Aramco Potential Requirements

Figure 5

The desired potential difference is achieved by making the structure negative with respect to remote earth. Module 2 described how current from a remote ground bed creates an area of influence, or potential gradient area, in the earth around a cathodically protected structure. The potential of the pipeline becomes increasingly negative as a reference electrode is moved away from the pipeline to a point where remote earth is reached.



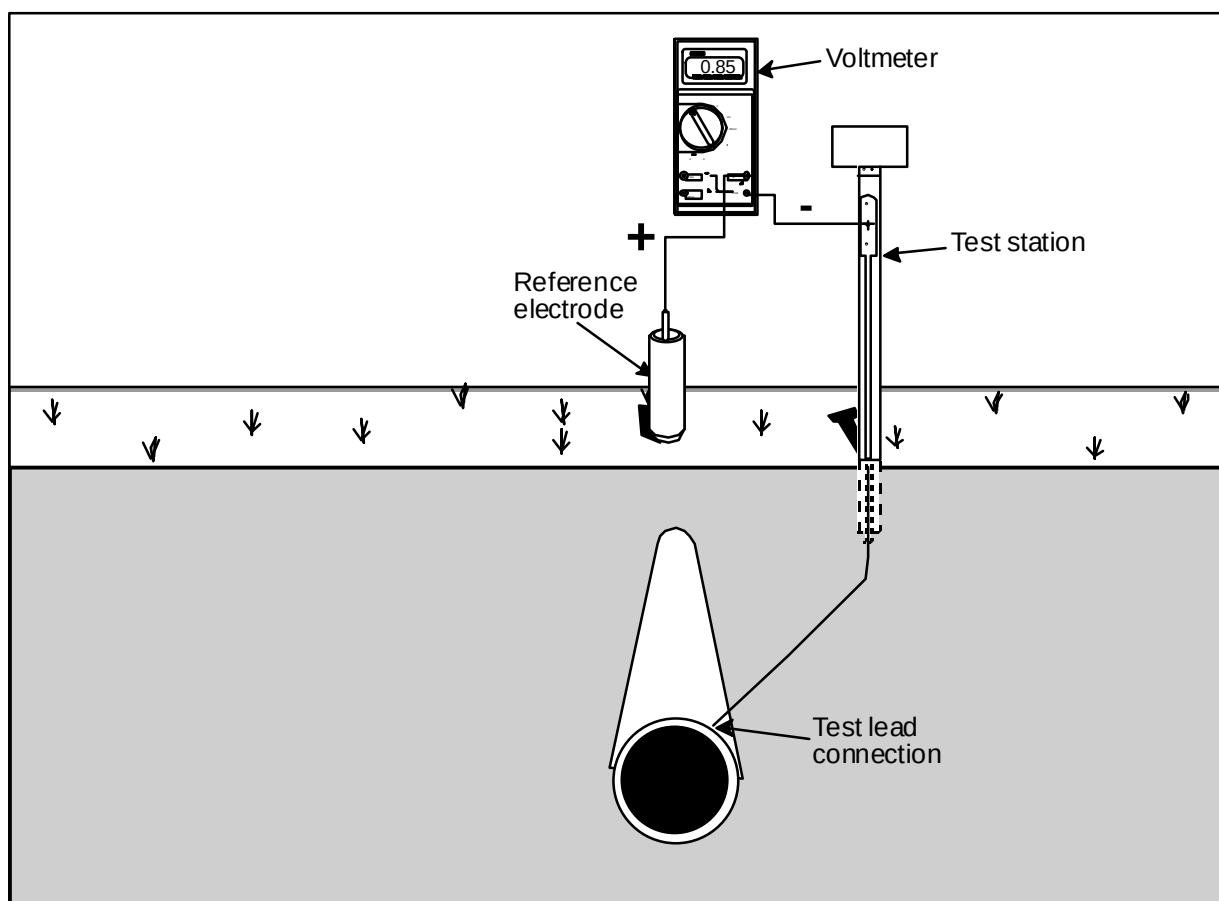
Potential Gradient Around a Protected Pipeline

Figure 6

Electrical potentials are measured through the use of a high input impedance voltmeter and a reference electrode. Ideally, the potential should be measured with the reference electrode as close to the pipeline's surface as possible; however, it is not possible to place the reference electrode at the surface of a buried pipeline.

The best way is to measure the potential between the pipeline and the earth at the ground surface directly above the pipeline as shown in Figure 7. The reference electrode is connected to the positive terminal of the voltmeter. The common (negative) terminal of the voltmeter is connected to the structure. The negative terminal can be electrically connected to a buried structure at a test station or directly to the structure at an above ground location.

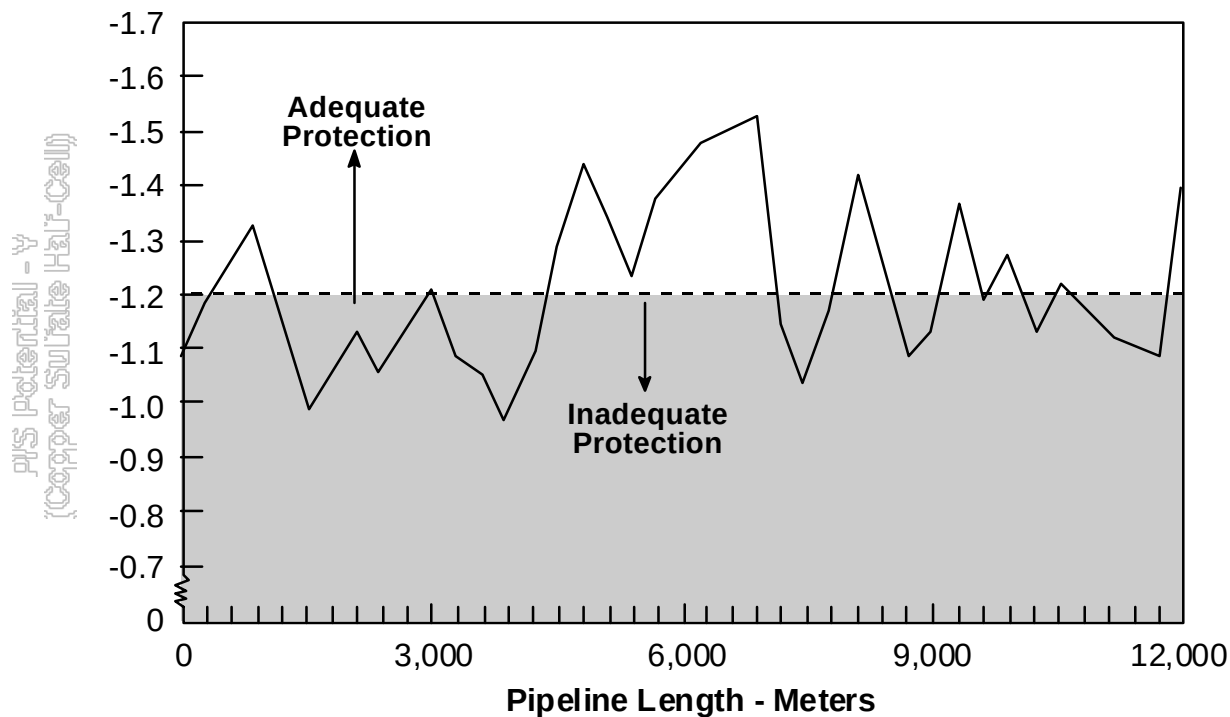
The voltmeter reading is a combination of the potential between the reference electrode and the soil and the potential between the pipeline and the soil. The potential between the reference electrode and the soil is constant. The potential between the pipeline and the soil can vary. When connected as shown, the potential reading will normally be positive. By convention, voltage readings are reported as negative numbers.



Technique to Measure Pipe-to-Soil Potential

Figure 7

To evaluate the degree of cathodic protection that is achieved, we must determine if enough cathodic protection current has been applied to protect the entire structure. The technique that is shown in the previous figure only measures the potential near the reference electrode; therefore, a potential survey of the entire pipeline is conducted to determine if a pipeline is adequately protected. A typical survey consists of the taking of potential readings at several locations, as shown in Figure 8. Any readings more negative than -1.20 volts (vs. Cu-CuSO₄) indicate adequate cathodic protection. Any readings more positive than -1.20 volts indicate possible corrosion zones. A procedure to measure pipe-to-soil potential of a pipeline is provided in Work Aid 2.



Typical Pipeline Potential Survey
Figure 8

Measuring Cathodic Protection Current

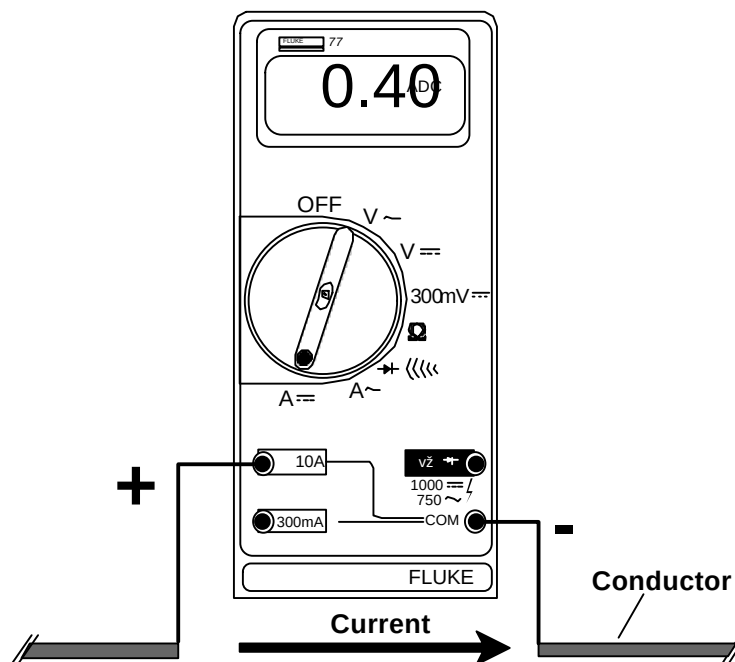
Two ways to determine current in a circuit are: (1) measuring amperes directly with an ammeter, or (2) measuring the voltage drop across a shunt and calculating the current. Either method can be used to measure the current output of the following:

- Anodes
- Cathodic protection rectifiers
- Temporary installations for current requirement tests

The following information describes instruments and techniques that are used to measure cathodic protection current.

Ammeter

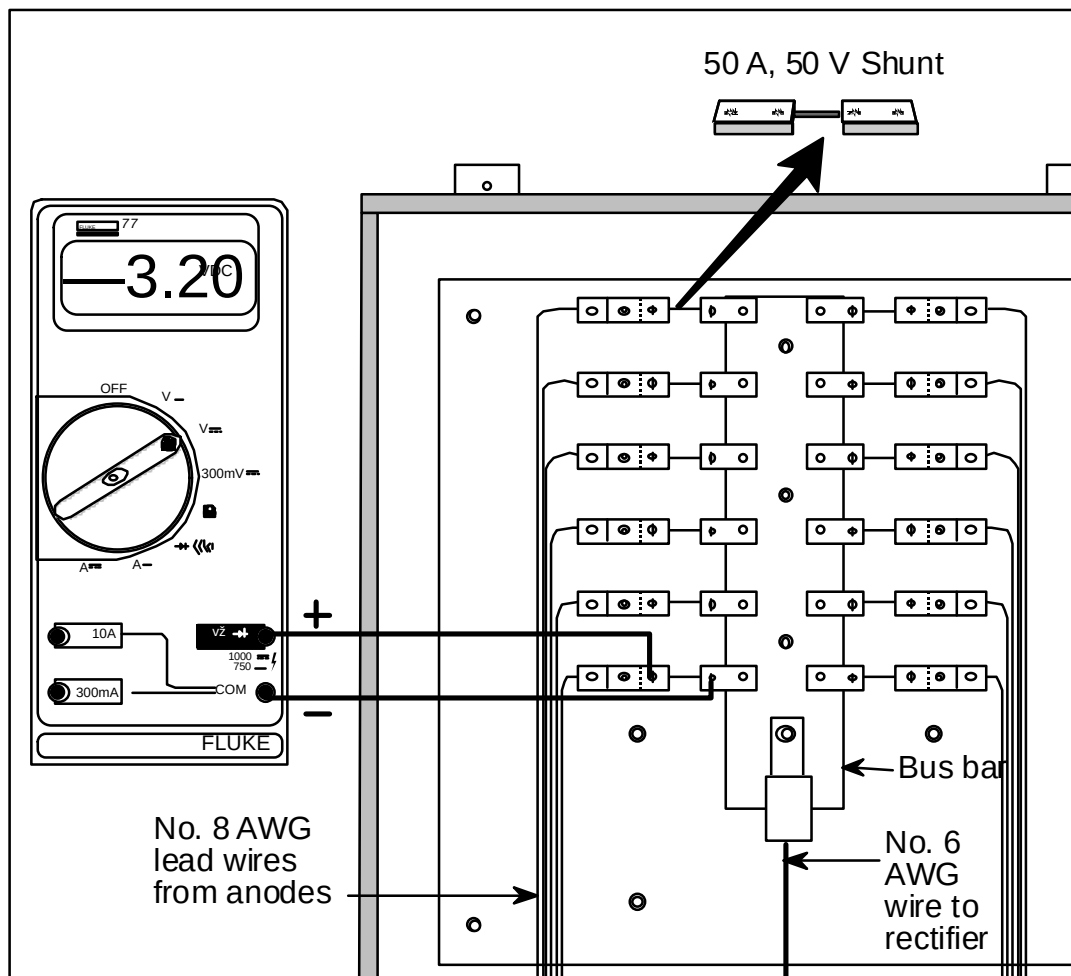
Ammeters are instruments that are designed to measure electric current. An ammeter must be placed within an electric circuit to measure current. Ammeters have relatively low internal resistance. They add very little resistance to the circuit so that there is negligible reduction in the total current that flows through the circuit. Special combination meters, or multimeters, have been developed for measuring current, voltage, and resistance over many orders of magnitude. Figure 9 shows a typical multimeter that is used by Saudi Aramco. Multimeters measure both alternating and direct current.



Multimeter Used as Ammeter
Figure 9

Shunt Currents

Galvanic and impressed current anodes are usually installed with shunt resistors in the junction box. Shunts allow the current output of both types of anodes to be measured without disturbing the system. The current that flows through a shunt produces a voltage drop, which can be measured with a multimeter (Figure 10). If the resistance of the shunt is known, the current output can be calculated through the use of Ohm's Law, $I = E/R$. For example, if a voltage drop of 3.20 volts is measured across a 1.0 ohm shunt, the amount of current flowing through the shunt is 3.20 volt/1.0 ohm, or 3.2 amperes.



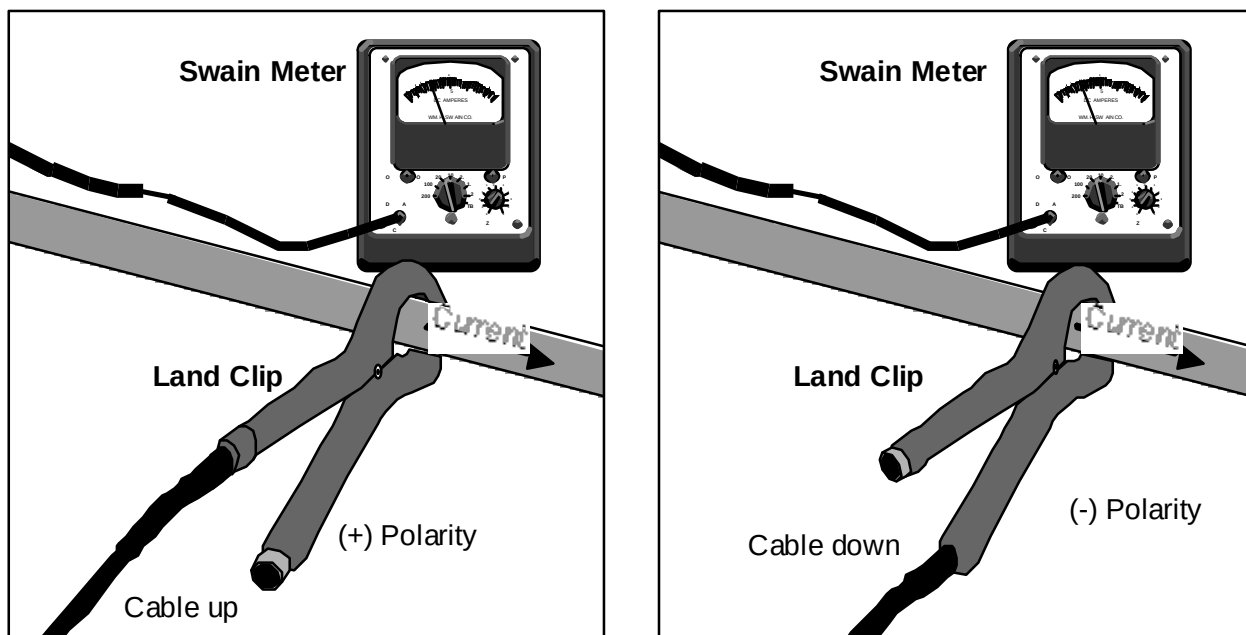
Measuring the Voltage Drop Across a Shunt Resistor

Figure 10

To determine the direction of current flow, it is important to observe where the positive and negative leads of the multimeter are attached to the shunt. A positive reading means that current is flowing from positive to negative through the shunt. A negative reading means that current is flowing from negative to positive through the shunt.

Clamp-On Ammeter

Electric current produces a small magnetic field as it flows through a conductor. The strength of the magnetic field is proportional to the amount of current that flows in the conductor. A clamp-on ammeter is used to measure the amount and direction of electric current based on the strength of this magnetic field. Figure 11 shows a Swain Meter with a 1-1/2" Land Clip. The Land Clip measures the average magnitude of direct or alternating current that flows in conductors up to 3/4" in diameter. The advantage of a clamp-on ammeter is that current can be measured by placing the clamp around an energized wire without opening the circuit to install a meter.



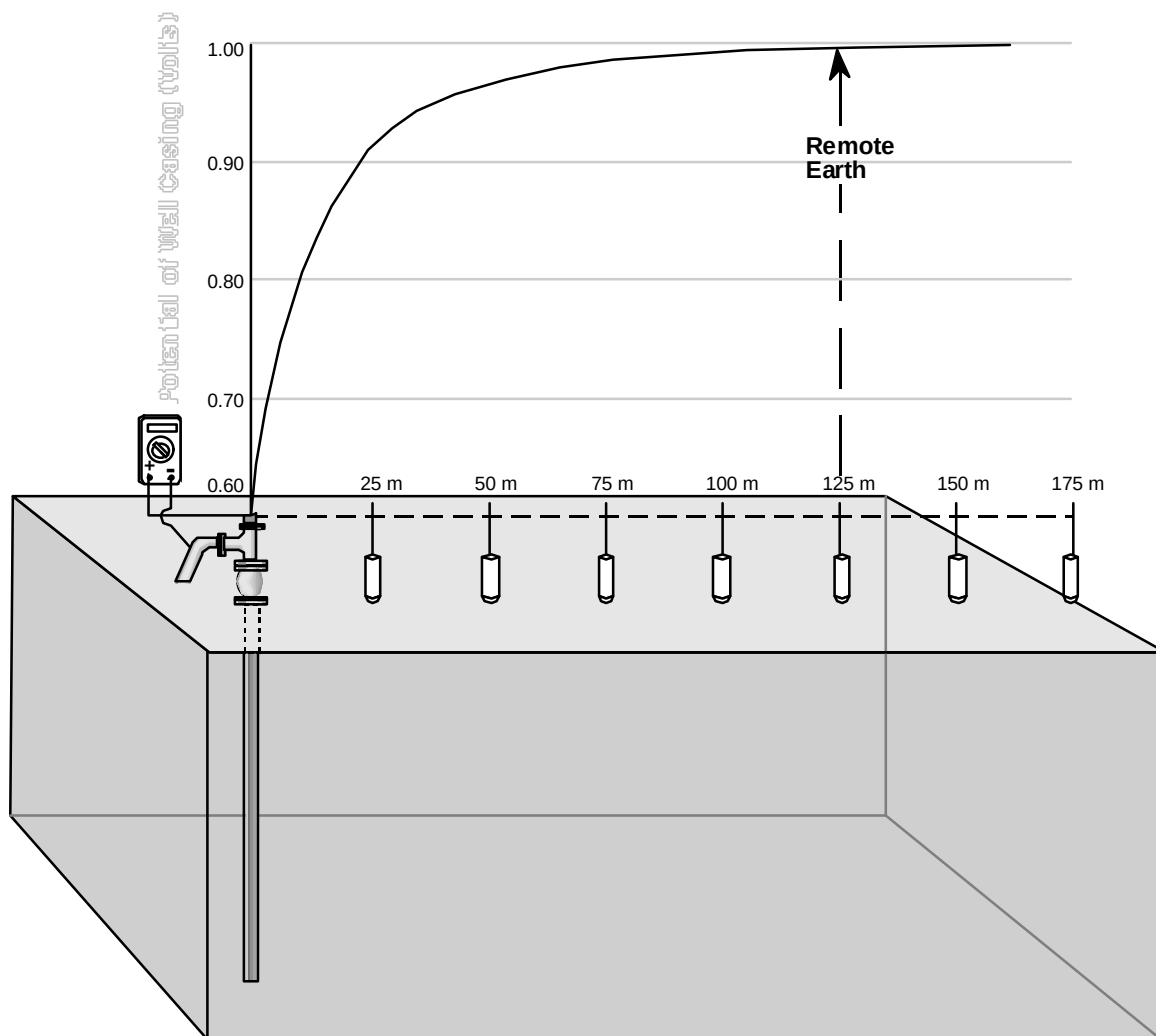
Swain Meter with a 1-1/2" Land Clip

Figure 11

Performing a Well Casing Survey

Measuring Well Casing Polarization Potential

Monitoring the effectiveness of cathodic protection for well casings is more difficult than for pipelines. For well casings, the potential difference along the external length of the casing cannot be measured without the expense of a casing potential profile as described in Module 3. A second, and less accurate, method of measuring casing potential involves the use of remote Cu-CuSO_4 readings. Successive potential readings are taken farther and farther away from the well casing (Figure 12). Each reading is taken immediately after turning off the current output from the rectifier. Remote earth is reached where there is no significant change in the readings.



Determination of Remote Casing Potential

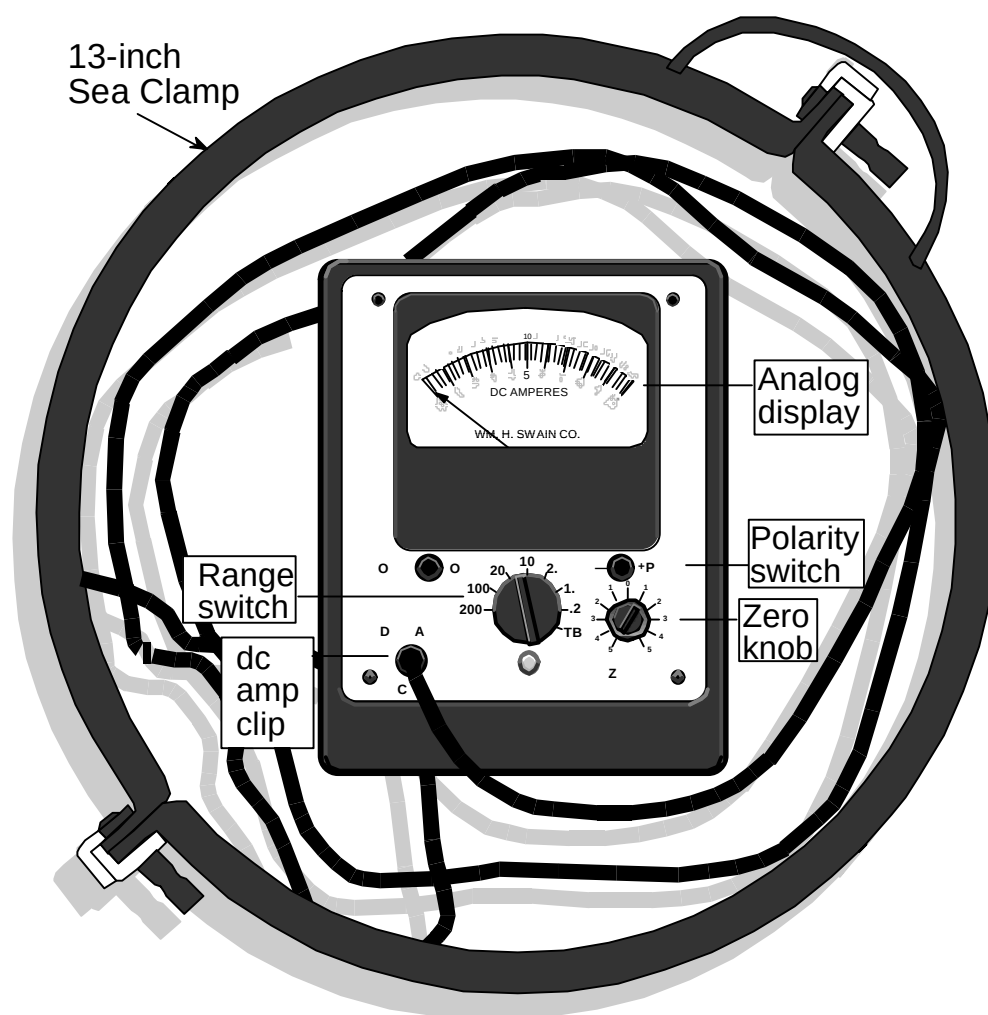
Figure 12

According to Saudi Aramco General Instruction 428.003, the cathodic protection criterion is to achieve a minimum of -1.0 volt casing-to-soil potential versus a remote Cu-CuSO₄ reference electrode with the current off for at least 10 seconds. This criterion involves determination of the polarized potential of the structure. Polarized potential can be determined by measuring the structure-to-earth potential immediately after turning off the current from all cathodic protection power sources. In this way, potential readings can be measured without "IR" drop which is caused by the flow of current in the circuit that includes both the structure and the soil. The procedure to perform a well casing survey is provided in Work Aid 4.

Measuring Cathodic Protection Current Returned by a Well Casing

In some cases, it is necessary to measure the cathodic protection current that flows on a well casing or on an above-grade flowline. It is important to know exactly how many amperes of current are being returned by the well casing to the CP power source when the CP system is "on." It is also important to verify that the well casing is returning less than five amperes to a nearby CP system when the well casing cathodic protection system is "off."

A Swain Meter and sea clamp (see Figure 13) are used to measure dc current that flows on a well casing or flowline. Saudi Aramco normally uses a 13-inch sea clamp to measure dc current on a flowline, and a 24-inch sea clamp to measure current on a well casing. The procedure to measure the cathodic protection current returned by a well casing is provided in Work Aid 4 (Step 3).



Swain Meter with a 13-inch Sea Clamp

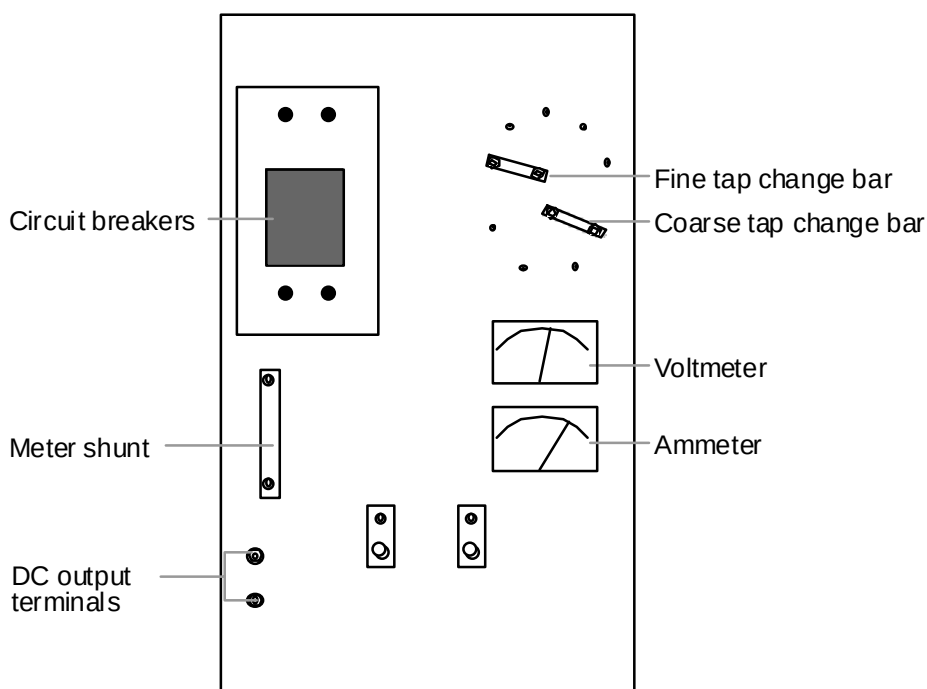
Figure 13

Inspecting the Condition and Operation of a Cathodic Protection Rectifier

Saudi Aramco uses three types of dc power sources--rectifiers, solar cells, and engine generators. Because of the magnitude of required current and the high soil resistivity in Saudi Arabia, 95% of all cathodic protection systems are powered by rectifiers or solar modules.

Rectifiers

Figure 14 shows a diagram of a rectifier panel. Note the locations of the dual meter, meter shunt, meter switch, and dc output lugs.



Typical Cathodic Protection Rectifier Panel

Figure 14

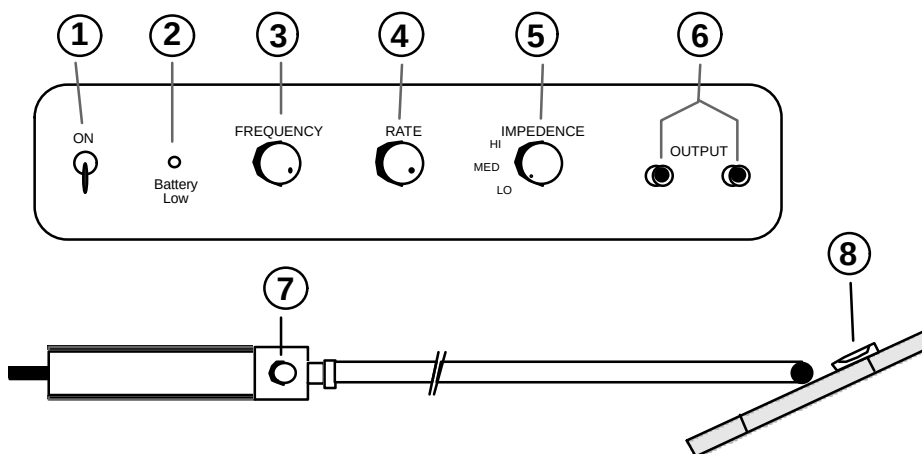
Saudi Aramco General Instruction 428.003 requires weekly inspection of rectifiers except for rectifiers on unmanned offshore platforms that are inspected monthly. During a rectifier inspection, the tap settings, voltmeter and ammeter readings are checked. The output voltage is verified by measuring the voltage across the dc output terminals of the rectifier. The ammeter reading is verified by measuring the voltage drop across the ammeter shunt and calculating the current. All readings are recorded on a data sheet. The procedure to inspect a rectifier is provided in Work Aid 5.

Work Aid 1: Procedure to Locate Buried Pipelines

This Work Aid contains a description of the Nilsson Model 715 pipe locator and a procedure for its use in locating a buried pipeline.

Operating controls and indicators for the transmitter and receiver are described in the following table. The locations of the controls and indicators are shown in Figure 20 below.

<u>Index No.</u>	<u>Control or Indicator</u>	<u>Description</u>	<u>Function</u>
1	ON-OFF	Flip switch	Turns transmitter on and off.
2	LOW BATTERY	Indicator	Turns on when the battery light voltage decreases to 9 - 10 volts.
3	FREQUENCY	Selector	Selects the proper pitch of the switch signal.
4	RATE	Selector	Adjusts the rate at which the switch signal is interrupted.
5	IMPEDANCE	Selector	Selects three output impedance switch ranges to give the best possible signal.
6	OUTPUT	Binding	Used to connect the transmitter posts to the pipeline to be located.
7	ON-OFF/VOLUME	Adjustable	Turns receiver on and off and switch adjusts volume of tone in head phones.
8	BUBBLE LEVEL	Indicator	Indicates horizontal and 45° inclination of receiver coil



Nilsson Model 715 Pipe Locator Panel

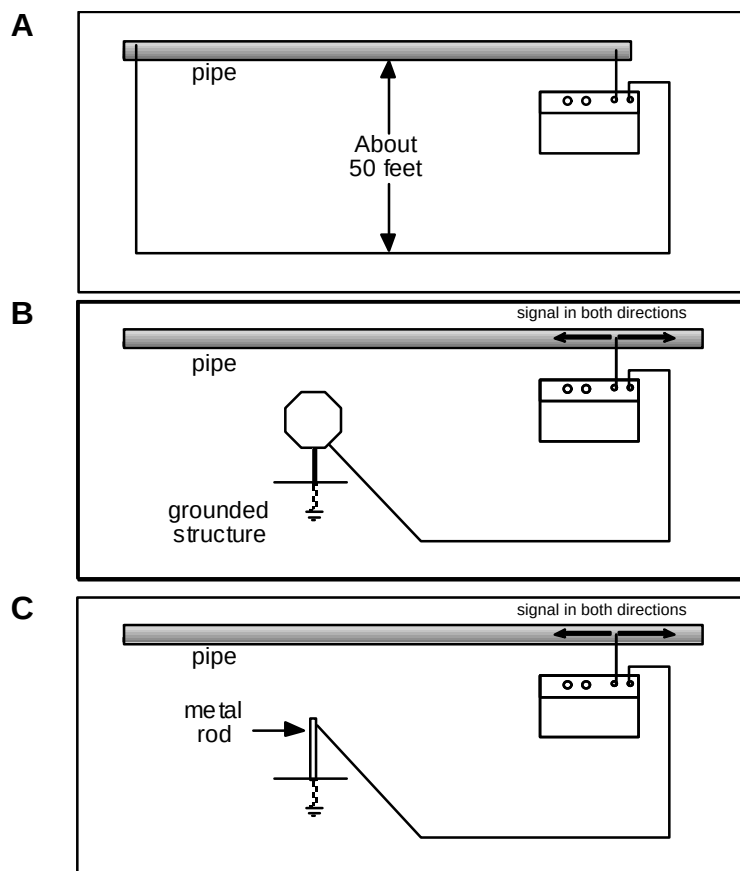
Figure 20

Preliminary Starting Procedures

Use the procedure in 1.1, 1.2, or 1.3 below on the basis of the existing conditions in the field.

1. Establish a series loop.
 - 1.1 Use the following procedure when two points are available at some distance apart on the pipeline.
 - a. Connect the bare end of an insulated copper wire to one OUTPUT binding post and tighten the binding post knob. Attach the opposite end of the wire to a point on the pipeline.
 - b. Locate another point on the pipeline that is at a considerable distance from the first point. Connect a second insulated wire from the other OUTPUT binding post to this point on the pipeline as shown in Figure 21A. Keep the wire about 15 m (50 ft.) from the probable path of the pipeline to minimize the signal from the wire.
 - c. Set the IMPEDANCE switch to LOW.
 - 1.2 Use the following procedure when one point is available on the pipeline and there is a nearby metallic structure that may be used as a grounding structure.
 - a. Connect the bare end of an insulated copper wire to one OUTPUT binding post and tighten the binding post knob. Attach the opposite end of the wire to a point on the pipeline.
 - b. Connect a second insulated wire from the other OUTPUT binding post to the grounding structure as shown in Figure 21B.
 - c. Adjust the IMPEDANCE switch until the best signal is obtained.
 - 1.3 Use the following procedure when one point is available on the pipeline and there is no convenient ground connection nearby.
 - a. Connect the bare end of an insulated copper wire to one OUTPUT binding post, and tighten the binding post knob. Attach the opposite end of the wire to a point on the pipeline.

- b. Drive a 0.5 m (18 in.) metal rod into the ground approximately 15 m (50 ft.) from the probable path of the pipeline. Connect a second insulated wire from the other OUTPUT binding post to the metal rod as shown in Figure 21C.
- c. Adjust the IMPEDANCE switch until the best signal is obtained.



Pipe Locator to Pipeline Connections

Figure 21

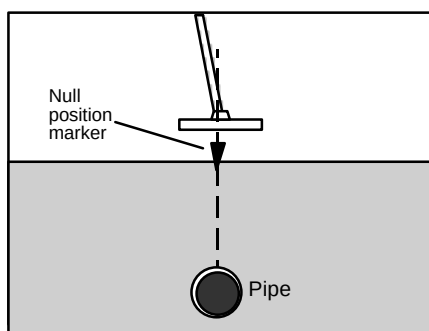
2. Achieve a distinctive signal.
 - a. Assemble the transmitter, receiver, and headphones. Turn on the transmitter and receiver.

Caution: After the transmitter has been turned on, do not touch the OUTPUT binding post or wiring. This contact could cause a shock, which is not dangerous but may be annoying, especially if the IMPEDANCE selector is in the HI position.

- b. Listen to the signal and adjust the FREQUENCY and RATE controls for the most distinctive tone under the present conditions. Set the receiver volume to the lowest level that can be heard comfortably. If a grounding structure is used, a signal will be heard in both the pipeline and the grounding structure.

Operating Procedures

3. Determine the depth and path of the pipeline.
 - a. Position the antenna disc close to the ground with the bottom facing downward. Center the bubble in the level.
 - b. With the bubble centered, move the antenna disc across the probable path of the pipeline. When the center of the disc is directly over the pipeline and parallel to it (Figure 22), a minimum signal will be heard. This position is referred to as the "null position." Mark the null position on the ground surface.

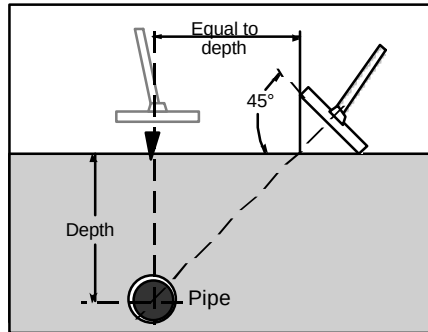


First Null Position

Figure 22

- c. After the null position is determined, tip the antenna disc to a 45° angle (bubble touching the outer edge of the ring on the level).

- d. Move the antenna disc horizontally from the first null position as shown in Figure 23 until another null position is obtained. Mark the second null position.



Second Null Position

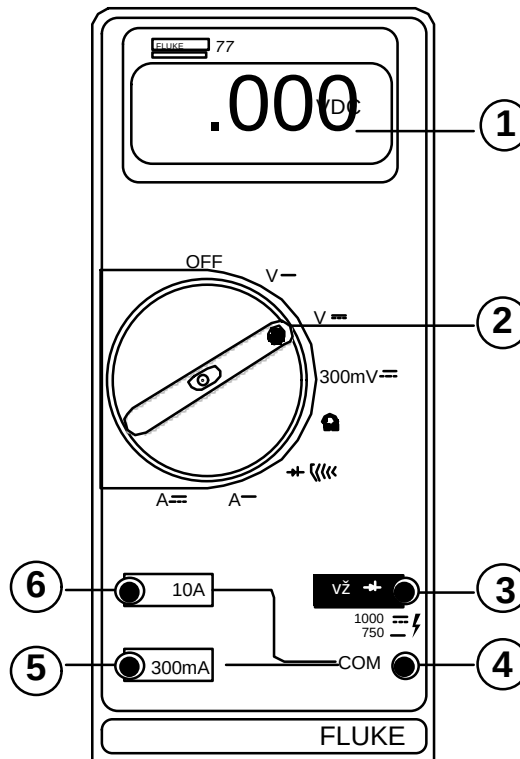
Figure 23

- e. Record the distance between the two null positions. This distance is equivalent to the depth of the pipeline below the first null position.

Work Aid 2: Procedure to Measure Structure-to-Electrolyte Potential

This Work Aid contains a description of the Fluke Model 77 Multimeter and a procedure to assist the Participant in measuring structure-to-electrolyte potential.

Operating controls and indicators for the Fluke 77 Multimeter are described in Figure 24.



Fluke 77 Multimeter

Figure 24

<u>Index No.</u>	<u>Control or Indicator</u>	<u>Description</u>	<u>Function</u>
1	DIGITAL DISPLAY	Indicator	Displays voltage and current readings.
2	FUNCTION SELECTOR	Rotary Switch	Selects 7 different functions or OFF. V  Volts ac V  Volts dc 300mV  Millivolts dc Ω Ohms (resistance, also conductance (1/Ω) in nanosiemens (nS)  Continuity or diode test A  Amps ac A  Amps dc
3	V Ω 	Volts, Ohms Diode Test	Input terminal used with the volts, mV (ac or dc), ohms, or diode test position of the function selector rotary switch.
4	COM	Common Terminal	Common or return terminal used for all measurements.
5	300mA	Milliamperes Input Terminal	Input terminal used for current measurements up to 300 mA.
6	10A	Amperes Input Terminal	Input terminal used for current measurements up to 10 A.

Preliminary Starting Procedures (Before you leave for the field)

1. Check the equipment.
 - a. Inspect the copper-sulfate electrode for damage or undissolved crystals. Make sure the copper rod inside the electrode assembly is clean and shiny. Clean it if necessary.
 - b. Make sure the electrode works properly. Test the electrode against another electrode that is kept in the office and used as a standard.
 - c. Turn voltmeter on and check battery. Check test leads for wear, and replace them if necessary.

Operating Procedures

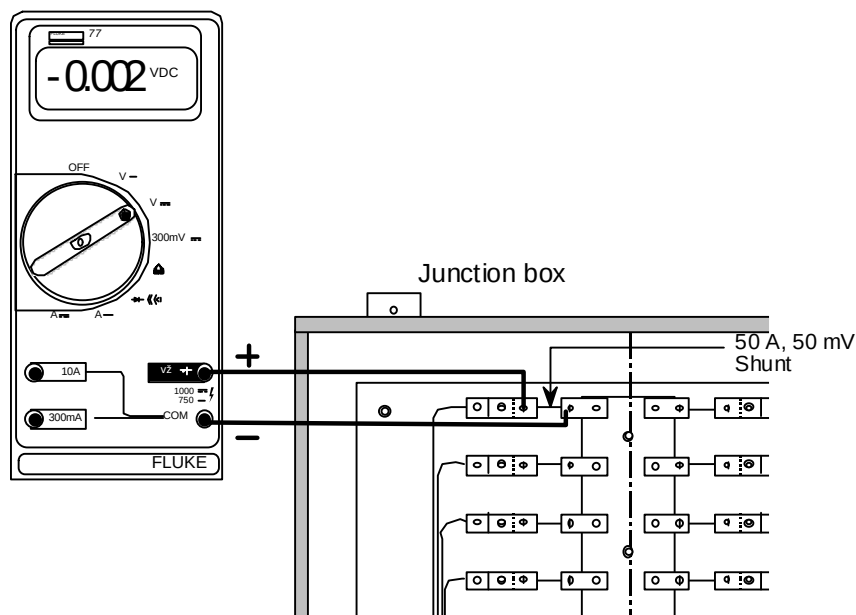
2. Measure the pipeline potential.
 - a. Set the FUNCTION SELECTOR to V.
 - b. Remove the cap from the end of the reference electrode, and place the plug of the reference electrode in mud or moist soil over the pipeline and about 0.6 m (2 ft.) from the test station.
 - c. Connect the positive lead of the voltmeter to the reference electrode.
 - d. Connect the negative lead of the voltmeter to the test station with the hex head nut.
 - e. Turn the meter to the lowest input impedance.
 - f. Measure the pipe-to-soil potential. (A reading that varies may indicate a poor connection, dry soil, or soil soaked with oil.)
 - g. Check the connections, and increase the input impedance until the highest reading is achieved. (The reading must be the same on two consecutive settings.)
 - h. Record the date, location, and voltage readings on the Well/Flowline Survey Data Sheet.
 - i. Remove the test leads. Remove the reference electrode from the soil, wipe off the dirt and replace the cap on the end of the reference electrode probe.

Work Aid 3: Procedure to Measure Cathodic Protection Current

This Work Aid describes the procedure to measure the current output of impressed current anodes.

Operating Procedures

1. Measure the anode current output (at the junction box).
 - a. Set the FUNCTION SELECTOR to V.
 - b. Connect the negative lead from the multimeter to the right side of the shunt for Anode 1 as shown in Figure 25. Connect the positive lead from the multimeter to the left side of the shunt (for the structure).



Multimeter Connection to Shunt Resistor in Junction Box

Figure 25

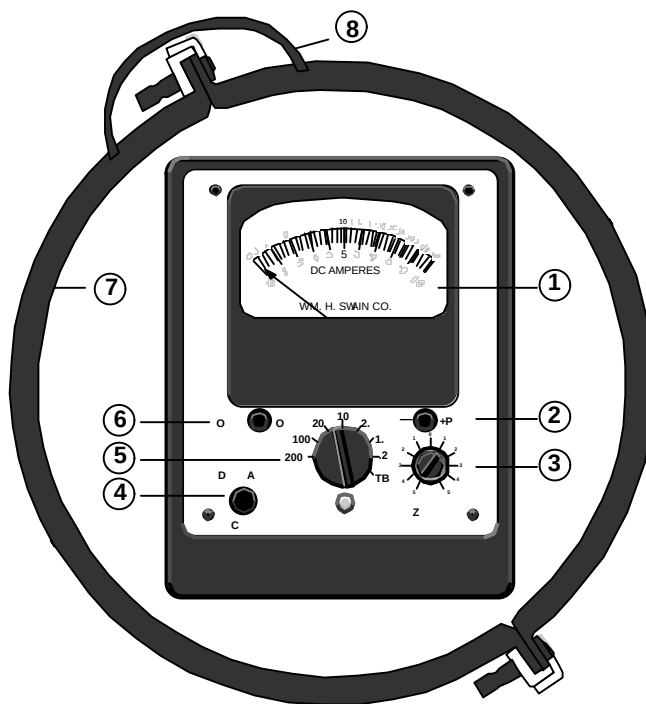
- c. Record the reading (in mV) in the CURRENT AFTER POLARIZATION column on the provided Anode Bed Survey form. Be sure to write the reading next to the proper anode number.
- d. Repeat Steps b. and c. for all of the remaining anodes.
- e. Multiply the voltage readings by the shunt rating constant (A/mV) to obtain the current output for each anode.

Work Aid 4: Procedure to Perform a Well Casing Survey

This Work Aid contains a procedure to measure the polarized potential of a well casing with a multimeter and Cu-CuSO₄ reference electrode, and a procedure to measure the cathodic protection current with a Swain Meter and 13-inch sea clamp.

Operating controls and indicators for the Swain Meter are described in the following table. The locations of the controls and indicators are shown in Figure 26 below.

<u>Index No.</u>	<u>Control or Indicator</u>	<u>Description</u>	<u>Function</u>
1	ANALOG DISPLAY	Indicator	Displays current readings.
2	POL	Switch	Sets the meter polarity.
3	ZERO	Knob	Sets electrical zero.
4	DC AMP CLIP	Jack	Connects sea clamp to meter.
5	RANGE (not labeled)	Switch	Selects current ranges from 200 A to 200 mA. TB setting is for testing the battery.
6	ON-OFF	Flip switch	Turns transmitter on and off.
7	--	Sea Clamp	Encircles pipe.
8	--	Bridle	Position indicates + or - current.

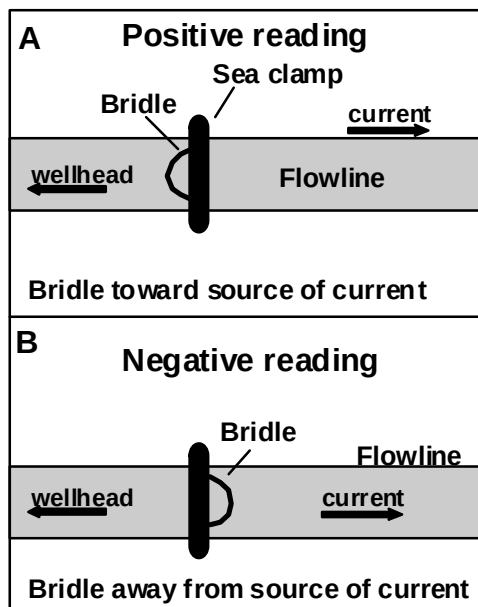


Swain Meter
Figure 26

Procedure

1. Record the rectifier output.
 - a. Two pairs of Participants should go to the cathodic protection rectifier.
 - b. With the rectifier "on," record the voltage and current readings from the rectifier voltmeter and ammeter on line 1 of the Well Casing Annual Survey form.
 - c. One pair of Participants will be given a multimeter, reference electrode, two lead wires, and a liter of water. This pair will go to Well No. 49 while the other Participants (or Instructor) remain at the rectifier.
2. Measure the polarization potential.
 - a. Set the FUNCTION SELECTOR on the multimeter to V.
 - b. Connect the shortest lead from the negative terminal of the multimeter to the well casing. Connect the longest lead from the reference electrode to the positive terminal of the multimeter.
 - c. One Participant should take the water and reference electrode approximately 150 meters east of the wellhead, remove the cap from the end of the reference electrode, and place the plug of the reference electrode in mud or moist soil. If the soil is not moist, saturate the soil around the electrode with water.
 - d. With the rectifier "on," the Participant at the wellhead should measure the casing potential. Record the potential reading (in mV) on line 2 of the form. A reading that varies may indicate a poor connection.
 - e. After recording the "on" reading, the Participant at the wellhead should signal the Participants at the rectifier to turn the rectifier "off." Ten seconds after the rectifier is turned off, record the casing potential reading on line 6 of the form. Signal the Participants at the rectifier to turn the rectifier "on."
 - f. On the form, the Participant with the reference electrode should draw a sketch of the location where he placed the reference electrode. Then he should leave the water container at the spot where he placed the reference electrode and return to the wellhead.

3. Measure the cathodic protection current returned by the well casing.
 - a. Plug the sea clamp into the CLIP jack of the Swain Meter. Place the POL switch in the + position. Turn the RANGE switch to 20 A. Move the ON/OFF switch to ON to turn on the meter.
 - b. Hold the sea clamp away from the flowline. Rotate the ZERO knob until the indicator reads 0.
 - c. Place the sea clamp around the flowline with the bridle pointing to the wellhead as shown in Figure 27A. Adjust the RANGE switch setting up or down to get the most accurate current reading. Record the current reading on line 3A of the Well Casing Annual Survey form. If the current flows from the well to the flowline, record the current as positive on the form. If the current flows from the flowline to the well, record the current as negative on the form.
 - d. Signal the Participants at the rectifier to turn the rectifier "off." Record the current reading on line 7A of the form, then signal the Participants at the rectifier to turn the rectifier "on."



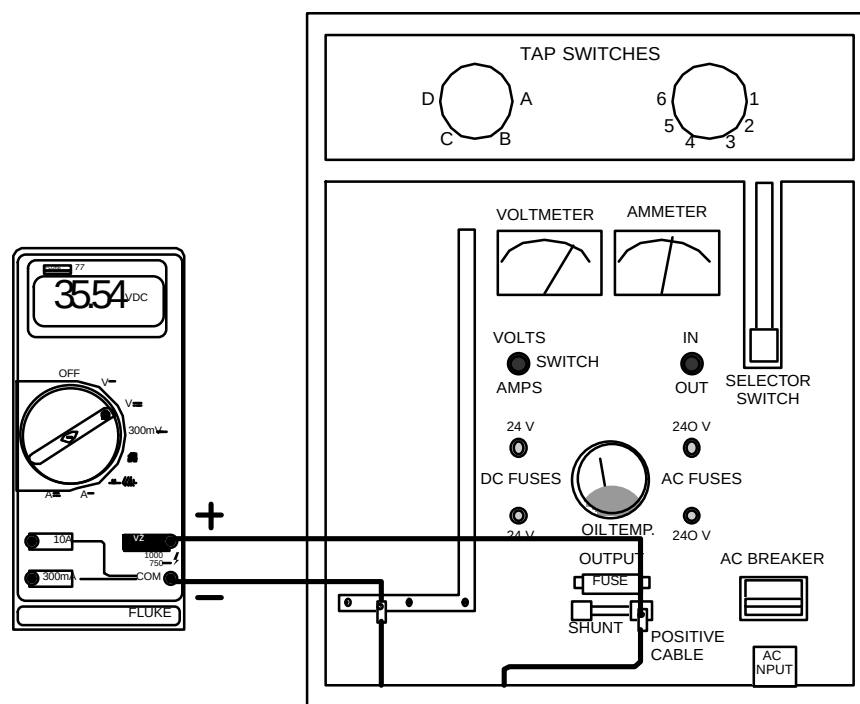
Measuring Current with a Swain Meter
Figure 27

Work Aid 5: Procedure to Inspect the Condition and Operation of a Cathodic Protection Rectifier

This Work Aid contains the procedure to inspect the condition and operation of a cathodic protection rectifier.

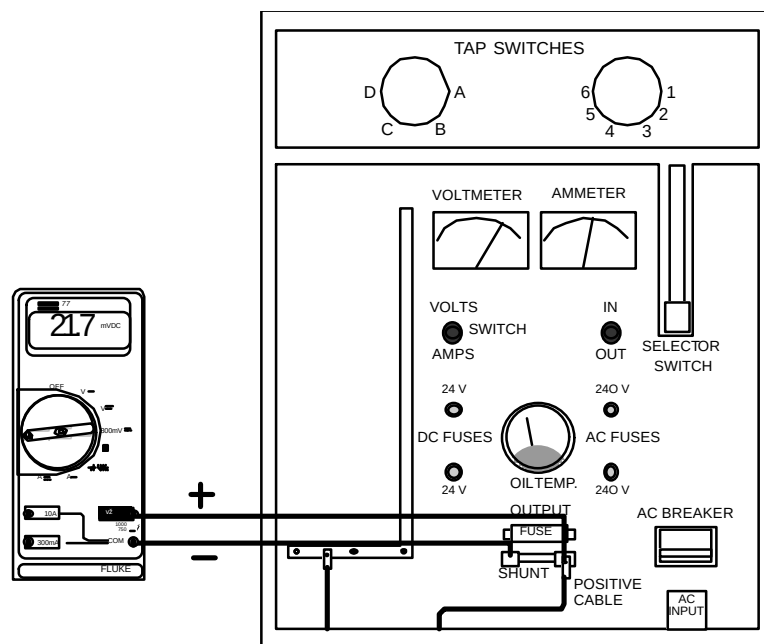
Procedure

1. Record the rectifier data on the data sheet. This data is usually found on the manufacturer's information plate on the inside of the rectifier door. Record the voltage and current readings from the meters on the rectifier panel.
2. Verify the rectifier voltage output.
 - a. Turn the rectifier off by switching the ac breaker to the "off" position.
 - b. Set the FUNCTION SELECTOR on the multimeter to V. Connect the positive and negative leads from the multimeter to the dc output terminals as shown in Figure 28.



Rectifier Panel
Figure 28

- c. Turn the rectifier on. Record the multimeter reading on the data sheet. Compare the multimeter reading to the rectifier's voltmeter reading.
 - d. Turn the rectifier off and remove the leads from the dc output terminals.
 3. Verify the rectifier current output.
 - a. Set the FUNCTION SELECTOR on the multimeter to 300mV.
 - b. With the rectifier off, connect the positive and negative leads from the multimeter to the meter shunt as shown below in Figure 29.



Multimeter Connections to Rectifier
Figure 29

- c. Turn the rectifier on and record the multimeter reading.
 - d. Turn the rectifier off and remove the test leads. Turn the rectifier on.
 - e. Multiply the voltage reading (in mV) by the shunt rating constant (A/mV) to obtain the current output of the rectifier. Record the calculated current on your data sheet.
 - f. Compare the calculated current output with the rectifier's ammeter reading.

glossary

area of influence	The area in which the potential of a structure exceeds the minimum potential required for protection.
current interrupter	A device that is used to switch a current source off and on automatically.
holiday	A discontinuity (pinhole or flaw) in a coated surface that exposes the metal substrate to the environment.
impedance	Measured in ohms, impedance is the total opposition to alternating current in an electric circuit. Impedance is equal to the square root of the sum of the squares of the resistance and reactance of the circuit.
IR drop	The voltage drop across a resistance in accordance with Ohm's Law.
native potential	The natural or "as found" potential of a structure before the cathodic protection system is energized.
polarization	The change in potential of a metal surface that results from the passage of current directly to or from the electrolyte.
polarization potential	The structure-to-earth potential at which corrosion ceases.
remote earth	The area(s) in which the structure-to-electrolyte potential change is negligible with change in reference electrode position away from the structure.
shunt	A low, calibrated, resistance that is connected between two points in an electrical circuit. A shunt is used to measure and control current.

Addendum A: Electrical Safety Instructions

Cathodic Protection work involves safety hazards to personnel unless proper safety measures are taken.

Electrical shocks are a hazard when you work with rectifiers. To avoid an electrical shock, follow these simple guidelines:

1. If you are working on the ac part of a rectifier, turn off and lock out the main ac power breaker for the rectifier.
2. Remove watches and rings when you perform electrical troubleshooting.
3. Always use insulated test leads.
4. Turn the unit off when installing or removing test leads, jumpers, etc.
5. Use a voltmeter to verify that the rectifier is de-energized before you do any work on the rectifier.
6. Avoid awkward or off balance positions that may cause you to fall into live circuits.
7. Keep hand tools out of "live" circuits.
8. Beware of large filter capacitors. An "off" unit may still be "hot."
9. REMEMBER: You can be killed while working with electricity unless proper safety guidelines are followed.

Burns are a hazard when you work with solar systems. Red hot metal can be created by the high current flow from the batteries and solar panels. To reduce the burn hazard follow these rules:

1. Remove watches and rings when you troubleshoot these units.
2. Isolate the solar panels and batteries before you begin your maintenance work.
3. Avoid awkward or off-balance positions that may cause you to fall into a live circuit.
4. Use insulated hand tools.