# **Basic Course** Chapter 5 – Potential Measurements

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**Appalachian Underground Corrosion Short Course** 

### Why Are We Here?



- I love corrosion (or the lack of corrosion).
- My boss sent me.
- My company offered to pay for it.
- This is my 2<sup>nd</sup> time.
- I know the instructor and plan to heckle him during his presentation.
- When is lunch?

# **Potential Measurements**

- Accurate potential measurements are critical to many areas of corrosion control work on underground structures.
- Inaccurate potential readings can lead to entirely incorrect conclusions regarding the need for corrosion control or the performance of a cathodic protection system.

# **Chapter 5 Material**

- An overview of instrumentation requirements.
- Reference electrodes used in certain potential measurements.
- Types of potential measurements.
- Potential measurement techniques.
- Polarization effects.
- Criteria for cathodic protection.
- Monitoring cathodic protection systems.

# **Voltmeters**



### Analog

- Moving needle
- Digital
  - Electronic digital readout





# **Analog Voltmeters**

- With the probes unconnected (switch open) – no current can flow through the circuit.
- 2. With no current flow, the coil generates no magnetic field pointer at zero.
- 3. Connect the probes (switch closed) and current flows through the coil.
- 4. Current creates a magnetic field in the coil.
- 5. The greater the current, the greater the magnetic field the higher up the dial the pointer moves.





# **Digital Voltmeters**



- Entirely electronic
- Digital readout
- Input resistance is typically very high (>10 Megohms)
- Current taken from external circuit is very small
- Very little voltage drop through external circuit



# Effect of Voltmeter Resistance

- The internal impedance (R<sub>i</sub>) of the voltmeter used must be high with respect to the external circuit resistance (R<sub>e</sub>) if accurate results are to be obtained.
- The accuracy of the meter depends on the ratio of the meter impedance to the external resistance.
- (R<sub>e</sub>) can be several thousand ohms.



# True Pipeline Potential = -0.950v<sub>cse</sub>

- External resistance
  - 2500 ohms
- Internal resistance
  - 100,000 ohms
- Meter reading
  - -0.927V

- External resistance
  - 2500 ohms
- Internal resistance
  - 1,000 ohms
- Meter reading
  -0.271V

# True Pipeline Potential = -0.950v<sub>cse</sub>

Е<sub>м</sub>

R<sub>M</sub>

E<sub>ACC</sub> = Accurate potential in volts

$$E_{ACC} = E_{M \times} \frac{R_{M} + R_{EXT}}{R_{M}}$$

- Voltmeter reading in volts
- Voltmeter resistance in ohms
- R<sub>EXT</sub> = Resistance of external circuit in ohms
  - Meter reading
     -0.271V

$$E_{ACC} = 0.271 \times \frac{1000 + 2500}{1000}$$

= 0.271× 3.5 = 0.95 volts

Meter reading
 -0.927V

 $\mathsf{E}_{\mathsf{ACC}} = 0.927 \times \frac{100,000 + 2500}{100,000}$ 

= 0.927 × 1.025 = 0.95 volts

### Ohm's Law I = E / R

- The higher the input impedance (R), the lower the display operating current.
- The lower the operating current, the lower the IR drop through  $R_e$ .
- More accurate potentials.

### No, thanks – I don't do math

#### • Conclusion:

- Use a good high resistance voltmeter!
- "When taking a potential measurement with a digital voltmeter, the voltmeter resistance is so high (typically 10 megohms or more) that external circuit resistance should seldom be a problem."

# **Reference Electrodes**

- A reference electrode is simply a device which is used to contact earth or water and to which the test lead from the voltmeter is connected.
  - Must be able to give repeatable and comparable readings
- Most common in corrosion work on underground structures:
  - Cu-SO<sub>4</sub> copper-copper sulfate half cell

# **Reference Electrodes**

- A reference electrode is one half of a corrosion cell

   consisting of a metal in a solution of it's metal
   ions.
- The "half cell" potential is constant if the concentration of metal ions in the solution around the metal remains constant.
- This is achieved by having a constant concentration of copper ions (saturated) in the solution around the copper rod.



### **Precautions**

- Keep solution saturated
  - Extra crystals to ensure solution stays saturated
- Use distilled water
- Copper rod will gradually become encrusted
  - Clean with sandpaper or dip in 10% nitric acid
- Keep porous plug covered when not in use
- Replace solution if it becomes discolored or "milky"
- Keep an extra unused half cell for calibration 10mV

### Two Things to Remember:

#### 1. Temperature Effect

- Cu-CuSO<sub>4</sub> half cell is subject to change due to temperature.
- -0.0005V (<sup>1</sup>/<sub>2</sub> millivolt) per degree change from 77<sup>o</sup> F

### $E_{CSE}^* = E_{CSE} - 0.5 \text{ mv/}^{\circ}\text{F} (T - 77^{\circ}\text{F})$

At an electrode temperature of 87° F: At an electrode temperature of 57° F:

0.80V - (0.5 mV X 10° temperature rise above 77 °)

0.80V + (0.5 MV x 20° temperature drop below 77°)

= 0.800V - 0.005V = 0.795 Volt

= 0.800V + 0.010V = 0.810 Volt

### Two Things to Remember:

#### 2. Photoelectric Effect

- Cu-CuSO<sub>4</sub> half cell is subject to change due to sunlight.
- Usually more of a problem when the copper rod is not clean
- Can be checked by shading the electrode to see if there is any change in the voltmeter reading. (Keep shaded)

# **Other Reference Cells**

- Silver-silver chloride Ag-AgCl
  - For use in sea water
    - Off-shore pipelines and drilling platforms
- Does not contain a liquid solution
  - Core of silver gauze with a film of silver chloride.
  - Enclosed in a protective sleeve which allows free entry of sea water.

### Other Reference Cells

• The ½ cell potential of the saturated silver/silver chloride reference electrode in 25 ohm-cm seawater is 0.050V less than a copper/copper sulfate reference electrode.

-0.84 volt to silver chloride in seawater =
 -0.89 volt to copper sulfate

# **Conclusions**

- Leaving a ½ cell in your vehicle overnight during cold weather can impact the accuracy of measurements.
  - Temperature effect
  - Frozen solution can damage electrode
- Leaving a ½ cell in your vehicle during hot weather or in direct sunlight can impact the accuracy of measurements.
  - Temperature and photoelectric effect
- Not keeping your ½ cell clean can impact the accuracy of measurements.

### **Electrode-to-Earth Resistance**

• Contact resistance between the reference electrode and the earth is usually the cause of high external resistance requiring the use of high resistance

voltmeters.



# **Electrode-to-Earth Resistance**

#### • To reduce this:

- Scrape away dry surface soil to expose moist surface.
- Wet the surface with water.
- No contact with anything foreign.
  - Grass, weeds, etc. especially when working in wet conditions.
- Test leads should be well insulated and free of cuts, breaks, or scrapes.

### **Questions**?

- Voltmeters
- Reference Electrodes







# Structure-to-Earth Potential Measurements



# P/S Potentials

- A structure-to-earth potential measurement (pipe-to-soil potential [P/S]) is the most common type of measurement for underground corrosion control work.
- P/S potential is recorded using a high input resistance voltmeter (10 megohm or higher) with a reference electrode (half cell) as close as practical to the pipeline



### "My meter says -1.125V...so?"

- This potential measurement (V<sub>m</sub>) includes:
  - Pipe polarized potential (E<sub>p</sub>)
  - Voltage drop in the soil (IR soil)
  - Voltage drop in the pipe (IR<sub>pipe</sub>)

•  $V_m = E_p + IR_{soil} + IR_{pipe}$ 

• With CP current turned 'ON' the voltmeter measures the total potential difference without being able to distinguish the pipe polarized potential ( $E_p$ ).



• It is these IR drop voltages which must be taken into account for valid comparison to the criteria.

• 
$$V_m = E_p + IR_{soil} + IR_{pipe}$$

### And that's not all...



Bare Structures

- Depends on Depth
- Directly over the line is critical for accuracy.

 A 'close' ½ cell only sees a small portion as opposed to a 'remote' ½ cell.

AREA "SEEN" BY REFERENCE ELECTRODE ON A BARE STRUCTURE

FIGURE 5-4



### Remote Earth on Bare Structures

- The potential measured between the structure and the reference electrode reflects the average of widely spaced anodic and cathodic areas from long-line corrosion cells.
- Although useful for determining long line corrosion protection, it cannot be used as an indication of when complete protection is attained for all surfaces

### **Bare Structures**



- Age and condition
- Old, bare structure with no CP:

• -0.100V<sub>cse</sub> to -0.300V<sub>cse</sub>

 For any two points on a non-cathodically protected structure, the point with the most negative reading is anodic to the other.




## End of Period - Break

#### New and/or Coated Steel



 Non-cathodically protected new steel (and well coated steel) can have potentials:

-0.700V  $_{\rm cse}$  to -0.800V  $_{\rm cse}$ 

#### New and/or Coated Steel

- Because the amount of corrosion current flowing to or from a well-coated pipe is extremely small, there is little possibility of significant voltage drops in the earth around the pipe.
  - Reference electrode directly above the pipe is essentially the same as one at a remote earth.
  - Point to point changes along the surface above a coated pipe tend to be much more gradual than on bare pipe.

## **Cell-to-Cell Potential Measurements**

- Cell-to-cell potential survey is measurement between two reference electrodes (surface potential survey)
  - Identifies anodic areas on bare pipe in galvanic systems
  - Two types of cell-to-cell potentials sometimes used in conjunction with one another

# Measurements between two reference electrodes





**B – ALONG-THE-LINE MEASUREMENTS** 

#### Lateral Measurements

- If 'A' is positive with respect to 'B', current is flowing towards the pipeline.
- If 'C' is positive with respect to 'B', current is flowing towards the pipeline.



#### <u>Along the line Measurements</u>

• If 'B' is positive with respect to 'A', there is a tendency for current flow in the earth.



 Cell-to-Cell survey along the pipeline identifies current reversals indicating anodic areas (current flowing away from the area) Structure to Structure Potential Measurements

#### Used to check continuity

• If everything is in good working order there will be a reading on the voltmeter – the difference between the two potentials.



#### **Structure to Structure Potentials**

- If the Voltmeter reads zero, it is an indication that something is wrong.
  - Isolating joint is shorted
  - Isolating joint is OK, but there is a parallel metallic path around the isolating joint.
  - There is no CP (or the CP system is off) and both sides of the isolating joint are exactly the same. (highly improbable – but possible)





- Used to determine anodic (corroding) areas on non-cathodically protected pipe.
- Used in evaluating the performance of cathodic protection systems.

## Two Electrode Survey Method

- Leap-frog
- Polarity is key

Test	Pipeline Station No.	Potential Between Electrodes	Polarity of Forward Electrode	Pipe to Cu-CuSO <sub>4</sub> Potential
Pipe to Cu-CuSO₄ at Test Point at	672+15			-0.573
Cu-CuSO, at Test Point to Cu-CuSO, at	672+20	0.015	(+)	-0.588
Cu-CuSO, at Sta 672+20 to Cu-CuSO, at	672+25	0.023	(+)	-0.611
Cu-CuSO, at Sta 672+25 to Cu-CuSO, at	672+30	0.012	(-)	-0.599



#### Two Electrode Survey Method

- Very hard to record potentials and polarity
- An error at any one point will carry forward
- Stray currents and long line currents can also be present and impact potentials

## Single Electrode Survey Method



PART B – SINGLE ELECTRODE SURVEY METHOD

## **Close Interval Survey - CIS**



PART C - SOPHISTICATED PROPRIETARY COMPUTER - COMPATIBLE SURVEY SYSTEM

- Two reference electrodes are walked forward and measurements taken at "close-intervals"
- Potentials are recorded in the data logger and processed by computer

#### **Close Interval Survey - CIS**



DISTANCE ALONG PIPELINE

- Keep in mind the survey does not tell all the results
- "Lesser" anodic area in very low resistivity soil may be more actively corroding than a "major" anodic area in higher resistivity soil

## Now Let's add some CP -





## **Polarization Effects on Potential**

- What is polarization?
  - The deviation from the open circuit potential of an electrode resulting from the passage of current. (or Fig. 5-11)

#### • What is a polarization curve?

• A plot of current density versus electrode potential for a specific electrode-electrolyte combination.





## **Polarization and Depolarization**

- Bare or poorly coated pipe may be slow to polarize days or weeks.
- Well coated pipe typically fast to polarize (seconds to minutes).
- Bare or poorly coated pipe will depolarize rapidly compared to well coated pipe.

## **Criteria for Cathodic Protection**

- -0.850  $V_{cse}$  Criteria
- Discussed in chapter 3 (3-3) "How CP works"













#### Important Note:

- Avoid placing the electrode close to buried galvanic anodes
  - If placed over the anode it will include voltage drop in the earth caused by anode current discharge
  - Rule of thumb: Place the reference electrode at least 15 feet from the nearest galvanic anode
  - Check potentials on either side of the high reading point should clarify

## 100 mV of Polarization Criteria

- Where influencing current sources can be interrupted
- Current sources turned off for period of time

## 100 mV of Polarization Criteria



• Need at least 100 mV between the polarized potential and the depolarized potential

## 300 mV Shift Criteria

- This is not as sound a criterion as the -0.85 volt criterion (for steel) or the 100-millivolt polarization criterion.
- It has had reasonably good results.
- This criterion was dropped from the list of criteria in Section 6 of the NACE RP0169 (latest revision).
- Although still recognized and listed as a criterion for cathodic protection in Appendix D to Part 192 of the CFR, it is being interpreted by inspectors as 300 mV of cathodic shift after correction for IR Drop.
- In effect, they are requiring a 300-mV polarization shift.

## Monitoring Cathodic Protection Systems

- Potential Measurements used to periodically verify that CP is effective
  - Over the line potential surveys and at intervals between those surveys by monitoring test points

## Things You May See Again on Thursday

3. Name an angle complimentary to BDC:





#### <u>Good Things to Know</u>

- Don't put your reference cell directly over a galvanic anode when measuring pipe-to-soil potential.
- Keep your CuSO4 solution saturated with crystals, keep the Cu clean, and keep it capped when NOT in use.
- Just because your CuSO4 solution is blue doesn't mean it is OK. If you see no crystals, prepare new solution and clean the rod.
- □ 100 mV polarization and –0.85V P/S are the criteria; "300 mV transverse gradient" IS NOT.
- Voltage drop in the soil (IR) MUST be considered when using the 100 mV polarization criterion.
## <u>Good Things to Know</u>

- Structure-to-earth measurement requires a minimum of <u>1</u> reference cell.
- Depolarization is faster on a <u>BARE</u> structure than polarization.
- □ On a <u>BARE</u> structure with no cathodic protection, the more negative area is <u>ANODIC</u>.
- I Monitoring CP efficiency can be done by periodic over line surveys AND/OR potential measurement at test stations along the line.

A cell-to-cell survey is a good way to verify CP flow to a BARE structure.

## <u>Good Things to Know</u>

Internal resistance of a digital multimeter must be <u>HIGHER</u> than the external circuit resistance for accurate potential measurements.

## □ When using a digital multimeter:

- $\Box$  Pos (+) = Structure
- $\Box$  Neg (-) = Reference electrode.
- □ Usually have a negative reading.

□ For practical purposes, remote earth is pretty close on a well coated structure. Most of the resistance is in the coating.

