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The 100 millivolt polarization criteria, when to use it and when not to use it

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Objective

The 100 millivolt polarization criterion is a very useful criterion. It is used all around the world for pipelines and is quite successful in its application.

This presentation will discuss the criterion, when to use it, when not to use it and have a few examples of when this criterion is used incorrectly.

NACE CP Criteria for Pipelines from SP0169

Criteria for Steel and Gray or Ductile Cast-Iron Piping

- Criteria that have been documented through empirical evidence to indicate corrosion control effectiveness on specific piping systems may be used on those piping systems or others with the same characteristics
- A minimum of 100 mV of cathodic polarization. Either the formation or decay of polarization must be measured to satisfy this criterion.
- A structure-to-electrolyte potential of -850 mV or more negative as measured with respect to a saturated copper/copper sulfate (CSE) reference electrode. This potential may be either a direct measurement of the polarized potential or a current-applied potential. Interpretation of a current-applied measurement requires consideration of the significance of voltage drops in the earth and metallic paths.

100 millivolts of polarization

- This criterion states that adequate protection is achieved with “A minimum of 100 mV of cathodic polarization between the pipeline surface and a stable reference electrode contacting the electrolyte.
- The formation or decay of polarization can be measured to satisfy this criterion.”
- Of the three criteria, this criterion has the most sound fundamental basis.

How it works

- The corrosion rate decreases and the rate of the reduction reaction on the metal surface increases as the underground pipeline is polarized in the negative direction from the native potential.
- The difference between the corrosion rate (expressed as a current) and the rate of the reduction reaction is equal to the applied cathodic protection - CP current.
- These processes can be shown graphically in an E versus Log I diagram, referred to as an Evans Diagram.
- The slope of the anodic (corrosion) reaction is referred to as the anodic Tafel slope and typically has a value of about 100 mV per decade of current.

How it works - continued

- With this Tafel slope, the corrosion rate of a pipeline decreases by a factor of ten (order of magnitude) for every 100 mV cathodic shift in the polarized potential.
- An order of magnitude decrease in the corrosion rate of an underground pipeline typically is more than adequate to effectively mitigate corrosion.

How it works - continued

- The cathodic polarization also promotes beneficial changes in the environment at the pipe surface, such as reducing oxygen, increasing the pH, and moving halides such as chlorides away from the metal surface, further decreasing the corrosion rate.
- These beneficial changes in the environment at the metal surface are referred to as environmental polarization in that the environmental changes typically result in a shift in the free corrosion potential of the pipe in the negative direction.
- Thus, the total potential shift from the native potential (excluding voltage drops in the soil), includes components due to environmental polarization and cathodic polarization.

Polarization formation vs. decay vs. native potential

- The magnitude of the polarization shift can be determined by measuring its formation or decay.
- In order to determine the magnitude of the shift as a result of the formation of polarization, it is first necessary to determine the native potential of the underground pipeline at test locations before cathodic protection is applied.
- The potential measurement is then repeated after the cathodic protection system is energized and the pipeline has had sufficient time to polarize.

Polarization formation vs. decay vs. native potential - continued

- Typically, the on potential is continuously monitored at one test location directly following energization of the cathodic protection system and an off potential reading is made when there is no measurable shift in the on potential reading with time over a period of several minutes.
- The off potential is then compared with the native potential; if the difference is greater than 100 mV, then the 100 mV criterion has been satisfied at that location.
- Off potential readings are then obtained at the other test locations to determine whether the criterion is met at these locations.

Polarization formation vs. decay vs. native potential - continued

- The time required for sufficient polarization to develop is highly dependent on the nature of the pipeline (coating type and condition, underground environment, etc.) and the design of the cathodic protection system.
- From a practical standpoint, it is wise to re-examine the overall pipeline - CP system if a reasonable amount of polarization does not develop within a few hours of energizing the cathodic protection system.

Polarization formation vs. decay vs. native potential - continued

- An alternate method of assessing the formation of cathodic polarization is to measure the on potential immediately following energization of the cathodic protection system and then to re-measure the on potential after a few hours to days of operation of the CP system.
- If the on potential shifts in the cathodic (negative) direction by more than 100 mV, then it can be conservatively assumed that the criterion has been met.
- This is because the applied CP current generally decreases with time, decreasing the magnitude of the voltage drop (IR Drop).

Polarization formation vs. decay vs. native potential - continued

- Thus, the total shift in the on potential must be a result of the sum of additional cathodic polarization and environmental polarization of the structure; both of which reduce the corrosion rate of the structure and are included in the 100 mV of polarization in the criterion.
- If this method is used, it should be confirmed that the applied cathodic protection current decreased with time.

Polarization formation vs. decay vs. native potential - continued

- Measuring the positive potential shift associated with polarization decay that occurs following de-energizing the cathodic protection system is the most common method of determining the amount of polarization.
- When a cathodic protection system is de-energized, an instantaneous positive shift occurs as a result of the elimination of the voltage drop (IR Drop) in the soil.
- The potential measured at this time is referred to as the off potential and is used as the starting point for assessing the polarization shift.

Polarization formation vs. decay vs. native potential - continued

- There may be a spike in the potential reading immediately following interruption of the CP system as a result of inductive effects of the pipeline and CP system.
- This spike may last a few hundred milliseconds such that the off potential is typically measured 200 to 500 milliseconds following interruption.
- The potential will then exhibit an exponential decay in the positive direction as the capacitance across the structure to electrolyte boundary discharges.
- This component of the potential shift is the cathodic polarization of the structure as a result of the applied cathodic current.

Polarization formation vs. decay vs. native potential - continued

- A gradual linear decay in the potential will then occur over minutes to days to weeks as a result of a return of the environment at the pipe surface to a native condition.
- This component of the potential shift is the environmental polarization.
- To obtain the total polarization shift, the final potential after polarization decay is measured and subtracted from the off potential.
- If this difference is greater than 100 millivolts, then the criterion has been satisfied.

Application of the 100 millivolt polarization criterion

- The 100 millivolts polarization criterion is used on poorly coated or uncoated pipelines where it is difficult or costly to achieve either of the 850 mV criterion.
- In many cases, 100 mV of polarization can be achieved where the off-potential is less negative than 850 mV Cu-CuSO4.
- The application of the 100 mV polarization criterion has the advantage of minimizing coating degradation and hydrogen embrittlement, both of which can occur as a result of over protection.

Application of the 100 millivolt polarization criterion - continued

- In piping networks, the 100 millivolt polarization criterion can be used for the older, poorly coated pipelines while a 850 millivolt polarized potential criterion can be used for newer (well coated) pipelines in the network.
- Because of its fundamental underpinnings, the 100 millivolt polarization criterion can also be used on metals other than steel where a specific potential for protection has not been established.

Limitations of the 100 millivolt polarization criterion

- There are a number of limitations with this criterion.
- The time required for full depolarization of a poorly coated or uncoated pipeline can be several days to several weeks, making the method very time consuming and leaving the pipeline unprotected for an extended period of time. Fortunately, much/most of the depolarization occurs within a few hours and it frequently is not necessary to wait for the full decay, except where the total polarization is very close to 100 mV. Once the criterion has been met, it is not necessary to continue waiting for further depolarization.
- At the other extreme, if a depolarization of less than 50 mV is measured within a few hours, it is questionable whether the 100 millivolt polarization criterion can be achieved. At this point, it may be prudent to assess whether a longer wait for total depolarization is justified.

Limitations of the 100 millivolt polarization criterion - continued

- The 100 mV polarization criterion is frequently used to minimize the costs for upgrading cathodic protection systems, and the associated increase in power costs, in areas with degrading coatings.
- Because of the complicated nature of the measurements and the additional time required, the costs of conducting surveys for the assessment of the 100 mV polarization criterion is considerably higher than for the 850 mV criteria.
- Thus, an economical analysis may be required to determine whether there is actually a cost savings associated with application of the 100 mV polarization criterion.

Limitations of the 100 millivolt polarization criterion - continued

- The 100 mV polarization criterion should not be used in areas subject to stray currents because 100 mV of polarization may not be sufficient to mitigate corrosion in these areas.
- It is generally not possible to interrupt the source of the stray currents in order to accurately measure the depolarization.
- All DC current sources affecting the pipeline, including rectifiers, sacrificial anodes, and bonds must be interrupted to apply this criterion.
- In many instances, this is not possible, especially on older pipelines where the criterion is most likely to be used.

Limitations of the 100 millivolt polarization criterion - continued

- The 100 mV polarization criterion should not be used on pipelines that contain dissimilar metal couples because 100 mV of polarization may not be adequate to protect the active metal in the couple.
- This criterion should not be used in areas where the intergranular form of external stress corrosion cracking, also referred to as high pH or classical SCC, is suspected.
- This is because the potential range for cracking lies between the native potential and 850 mV CuCuSO4 such that application of the 100 mV polarization criterion may place the pipeline in the potential range for cracking.

When to use the 100 millivolts polarization criterion

- Applying the 100 mV polarization criterion to an older/mature pipeline system.
- When coating disbondment is a concern. Typically on older/mature pipeline systems with bitumastic/asphalt enamel/coal tar enamel coatings.
- When adding CP/IR coupons to an older/mature pipeline system.
- To minimize interference with other pipeline systems.

Personal Experience in using the 100 millivolt polarization criterion

- I started using the 100 mV polarization criterion in the 1990's when I was working on some uncoated pipelines installed in 1948 & 1949.
- The pipelines were protected using a distributed ICCP system running about 125 miles – 210 KM.
- They were trying to get an 850 polarized potential on these uncoated lines and not having much luck in getting that potential.
- They were also having a tremendous amount of maintenance on the ICCP system due to the high current levels flowing through the cables and having multiple cable breaks and cable to anode splices failing.

Personal Experience in using the 100 millivolt polarization criterion - continued

- We spent 2 years in converting the pipeline to the 100 millivolt polarization criterion and upgrading the distributed ICCP system.
- The results were achieving a protective potential, lowering the overall output of the ICCP system and replacing the distributed system with a linear anode system.
- We also performed selective recoating in the heaviest populated areas to ensure public safety.
- This pipeline had over the years experienced 3 ruptures and multiple leaks and was under scrutiny by the regulators.

Personal Experience in using the 100 millivolt polarization criterion - continued

- Since that time I have been involved in multiple projects upgrading the CP systems on older/mature pipelines with aging coating systems and have been converting many of these pipelines to the 100 mV polarization criterion.
- It is not easy and is very time consuming and does not always have an immediate payback.
- The most difficult part of using the 100 mV polarization criterion is educating the pipeline owners and the government regulators about this criterion, explaining how it works, why it works and why we are not getting 850 millivolts on the voltmeter.

Thank you for your time – any questions/comments/suggestions /concerns?