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TWO HALVES OF A WHOLE: COATINGS AND CATHODIC PROTECTION

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Summary:

Coatings prevent corrosion by creating a barrier between the structure and the electrolyte. Cathodic protection works by changing the potential of the structure to interfere with the corrosion process. Both work together to protect the structure. Surveys can be done to evaluate the condition of the coating and of the cathodic protection. By combining data from multiple types of surveys, anomalies can be prioritized for repair. Specialized digital recorders are capable of performing cathodic protection and coating integrity surveys in one pass and storing that data with GPS co-ordinates for later analysis.

Corrosion has a global cost of billions of dollars every year. Corrosion of underground and underwater metallic structures such as pipelines and tanks can be managed. To protect underground metallic structures there are three main options; material selection, coating and cathodic protection.

Material selection begins in the design phase of a project. There is always a compromise between material, use and cost. There are corrosion resistant materials available for most situations but materials such as stainless steels are not often used due to expense and potential for corrosion underground.

Corrosion occurs when an anode and cathode are connected with a metallic path and an electrolyte. A coating helps to prevent corrosion by removing the structure from contact with the electrolyte. Ideally, a coating is perfect and will never allow the structure to contact electrolyte. However, reality is that a very good coating still has defects. These defects can occur during initial application or installation of the structure, or they can also come from later damage by soil/rock shifting or other parties digging near the structure. Given a 1m diameter pipe, 100m long with a good coating that is 99.999% perfect, the 0.001% coating defect represents a 30 cm² defect, or 30 separate 1 cm² defects.

Corrosion is often accelerated at a coating defect as it exposes a small area of the structure to act as an anode for the rest of the structure. The defect concentrates the corrosion current in a small area. The pipe in Figure 1 had a coating defect which allowed corrosion

pits to develop. This effect is of particular concern in AC hydro corridors as there is a direct relationship between corrosion rate and AC current density.

The other method used to prevent corrosion is to use cathodic protection to interfere with the electrochemical process by making the structure more electronegative. Cathodic protection is applied through sacrificial anodes or impressed current from rectifiers. Voltage and current requirements are determined by a number of factors including the soil resistivity and coating properties. Larger areas of bare structure require more cathodic protection current.

By using both coatings and cathodic protection together, the ability to prevent corrosion is greatly improved. Coatings provide a physical barrier between the structure and the electrolyte, however coatings always have some defects. Cathodic protection changes the potential of the structure to prevent corrosion at the coating defects. A better coating results in less cathodic protection current being required, fewer anodes or less rectifier output is needed; both of which result in lower cost for the structure owner. Using the same 1m diameter pipe above with an estimated current requirement of 20 mA/m^2 , one can calculate the current required for protection. With a coating effectiveness of 99.9%, the current required would be 6 mA. With a coating effectiveness of 99.999%, the current required would be 0.06 mA. Over a long stretch of pipeline and over time the energy savings can be significant with a better quality of coating. During design of the pipeline or other structure, the design engineer must take into account the cost of various coatings, the cost of cathodic protection and the ongoing maintenance costs of both. Current practice is to install the best coating possible and install a cathodic protection system that can be adjusted as needed.

Over time both coating integrity and cathodic protection levels can change. Construction in the area of the structure can damage the coating and change the soil resistivity. Seasonal changes can change the level of moisture in the soil, affecting the soil resistivity. Monitoring the coating integrity and the cathodic protection level is important to maintain the integrity of the structure.

There are a number of possible above ground coating integrity surveys. All involve generating a signal on the pipeline and surveying the line for voltage gradients. DCVG creates a DC pulse, often by interrupting the source of cathodic protection, and then walking the line with two electrodes looking for a voltage gradient in the soil. ACVG inputs an AC pulse in the soil; the surveyor also walks the line measuring AC voltage gradients. A Pearson survey is also similar to ACVG; using a higher frequency AC signal and registering the voltage gradient as an audible signal.

Defects in the coating generate an electrical signal in the form of concentric potential gradients emanating from the defect. The survey involves a surveyor walking along the line with two electrodes. When the electrodes are across the concentric voltage gradient lines a voltage is read between the two electrodes, as shown in Figure 2. The closer one electrode is to the centre of the defect, the larger the voltage reading. The electrodes



Figure 1 – Pitted pipe at coating defect

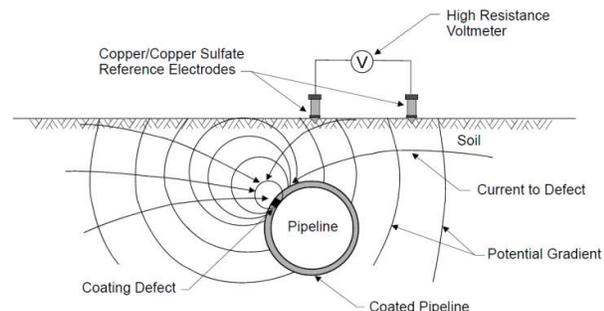


Figure 2 – Gradient lines from defect
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can be transverse to the pipe as shown in Figure 3 or along the axis as shown in Figure 4. A transverse survey produces a spike where the defect exists as the two electrodes are capturing the potential across the most gradient lines. A survey along the axis produces a spike prior to the defect as one electrode is near the defect and the second is able to capture the most gradient lines. The potential reading then crosses zero as the two electrodes are 'balanced' at the centre of the defect. Finally, as the surveyor moves away, a valley is shown after the defect as the electrodes are now reversed.

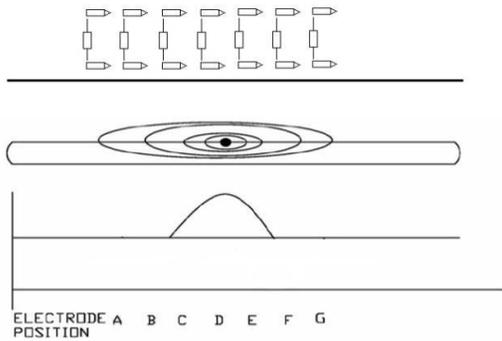


Figure 3 – Gradient pattern for transverse survey

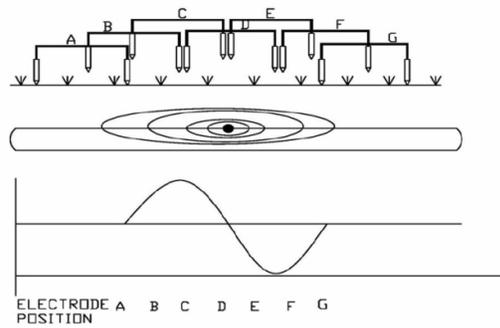


Figure 4 – Gradient pattern for survey along axis

A knowledgeable surveyor can approximate the shape of the defect by observing the shape of the gradient found. With DCVG, the size of the defect can be approximated based on the magnitude of the gradient compared to the DC signal strength (%IR).

The signal from the defect has a limited strength. This is partially dependant on the signal generated, depth of pipe and soil conditions. It is possible for small defects to be missed in voltage gradient surveys. It is possible to calculate the effect of a theoretical equivalent hemisphere. According to Ohm's law, $V=IR$, there is a direct relationship between potential and resistance.

Assume a defect has a similar surface area to a hemisphere with a defect length equivalent to $2r$. The total resistance through earth of an electrode is $R_{\infty} = \frac{\rho}{2\pi r}$ with ρ being the soil resistivity and r being the radius of the sphere. Finding the resistance of the hemisphere at distance R_1 is accomplished with equation $R_1 = \frac{\rho}{2\pi} \left(\frac{1}{r} - \frac{1}{R_1} \right)$ which then gives

the fraction of total resistance at $\frac{\frac{1}{r} - \frac{1}{R_1}}{\frac{1}{r}} = 1 - \frac{r}{R_1}$. This can be solved to reflect a percentage x as $R_1 = \frac{100r}{100-x}$. This relates the size of the defect to the size of the sphere where most of the signal can be seen.

Using the calculation for R_1 the distance from the hemisphere/defect where 95%, 99% or 99.5% of the resistance or potential is read as:

| | Distance to read the % of total resistance | | |
|---------------|--|------|-------|
| Defect radius | 95% | 99% | 99.5% |
| 5mm | 0.1m | 0.5m | 1m |
| 30.9mm | 0.6m | 3.1m | 6.2m |
| 50mm | 1m | 5m | 10m |
| 100mm | 2m | 10m | 20m |

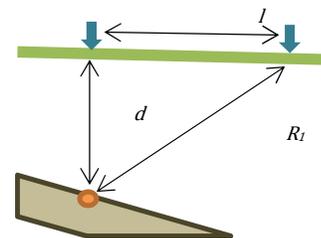


Figure 5 – Probe spacing & depth

When performing a voltage gradient survey, one electrode is on top of the pipe at depth d and the second is l distance away as shown in Figure 5. This can be inserted into the equation to calculate the probe spacing needed to capture x percentage of the total resistance or potential $R_1^2 = d^2 + l^2$.

| | | Probe spacing for voltage gradient at a depth of 1.5m | | |
|---------------|-----------------------|---|------------|------------|
| Defect radius | Surface area | 95% | 99% | 99.5% |
| 5mm | 0.79 cm ² | Won't read | Won't read | Won't read |
| 30.9mm | 30 cm ² | Won't read | 2.7m | 6.0m |
| 50mm | 78.5 cm ² | Won't read | 4.8m | 9.9m |
| 100mm | 314.2 cm ² | 1.3m | 9.9m | 19.9m |

The voltage gradient survey is unable to detect a very small defect as the sphere of influence is also small. In the chart above, the 5 mm radius defect is not detectable. The 50 mm defect will show at the surface as a small potential and a probe spacing of 5 m will capture 99% of the resistance. A larger defect is more visible as it requires a larger probe spacing to capture 99% of the resistance. Figure 6 and Figure 7 show the equivalent hemisphere of a small and large defect.

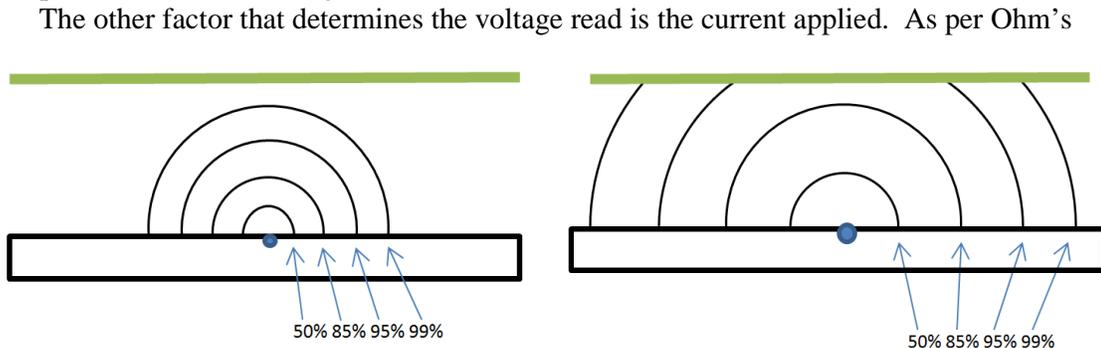


Figure 6 – Small defect

Figure 7 – Large Defect

law, if the current is low, the voltage is low for the same resistance. When performing DCVG, it is necessary to ensure that a large enough current is provided to show a voltage gradient. A DC signal of at least 300 mV is desired, and can be easily verified by reading the voltage difference between the ON and OFF voltages read at nearby test stations.

There are a few methods to confirm the level of cathodic protection. One is to keep rectifier logs, which are useful over time to track seasonal variations and to indicate if there have been any changes to the line that may affect the cathodic protection. Test station surveys monitor a number of points along the line and are also useful to monitor trends over time, but only specific points are surveyed, which is not necessarily indicative of the conditions on the rest of the pipeline. Figure 8 shows the effect of anodes installed at test stations. In this example, a test station survey would show that the pipe is protected, while the close interval shows the areas between the test stations are unprotected. The only survey method to confirm proper cathodic protection through the whole pipeline length is to perform a close interval potential survey, also known as CIS or CIPS.

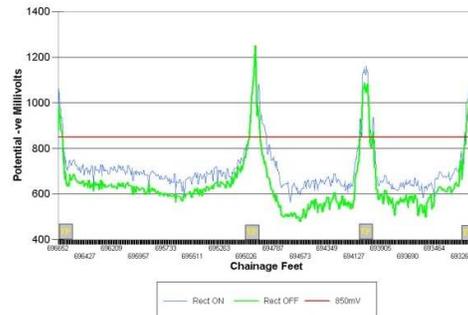


Figure 8 – CIPS with anodes at test stations

CIPS involves taking pipe to soil potential

readings along the line at intervals of 1m – 3m. In order to eliminate the effect of the soil resistance along the length of the line, the source of cathodic protection is rapidly cycled on and off. The instant off potential allows the surveyor to read the polarized potential of the pipeline by removing the effect of the cathodic protection current. Ohm's law, $V=IR$, shows that with the current from the cathodic protection at zero, the effect of the soil resistance between the cathodic protection and the surveyor's position is removed.

The readings from a CIPS are compared with criterion set for cathodic protection. NACE SP0169 states that there are three criterion. The first is a potential of -850 mV or more negative read by a copper-copper sulphate electrode with IR drop considered. The second is an instant off potential of -850 mV or more negative read by a copper-copper sulphate electrode. The third is a polarization of 100 mV or more; the difference between the native and the instant off potential. Some companies prefer to use more rigorous standards due to different conditions, such as -900 mV or -1000 mV.

CIPS and DCVG surveys both rely on a DC power source being turned on and off. The cathodic protection source itself can be used to perform both types of survey. Under most conditions, both surveys can even be performed at the same time. By performing two types of survey together, errors due to soil moisture, current output etc. are eliminated. Increased knowledge of the state of the corrosion protection allows the engineer to make better decisions and decreases survey costs by fielding one survey crew.

CIPS are used to confirm cathodic protection. DCVG surveys are used to check the integrity of the coating. As discussed, coatings and cathodic protection work together to prevent corrosion. Remove one form of protection, and the possibility of corrosion increases. Remove both, and corrosion becomes very likely.

When only a CIPS is performed, the level of cathodic protection is confirmed as shown in Figure 9. Any areas that are below criterion are a concern. The common response by a pipeline company is to increase the level of cathodic protection by installing anodes, rectifiers or increasing the output of the rectifiers.

When only a DCVG survey is performed, the coating integrity is checked as shown in Figure 10. This shows areas where there may be coating damage and provides an idea of the size of the defect. These areas can be dug and the coating repaired, which is an expensive process. However, every time a pipe is dug, the chances for further coating damage are increased.



Figure 9 – CIPS data

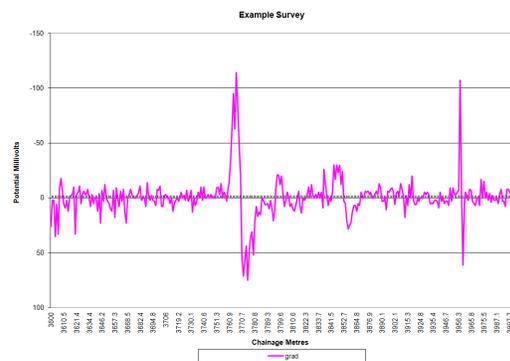


Figure 10 – DCVG survey data

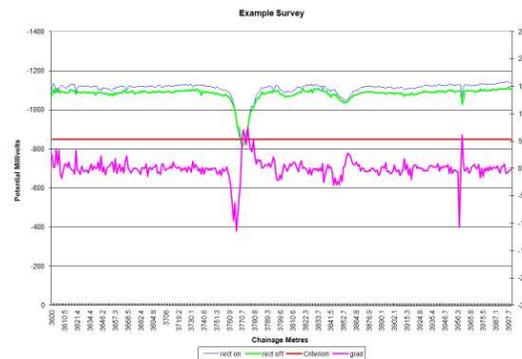


Figure 11 – Combined survey data

By combining both close interval and voltage gradient data, areas of concern are more apparent as in Figure 11. Areas with acceptable cathodic protection and no sign of voltage gradients are protected twice against corrosion. Areas with some coating damage and acceptable cathodic protection often do not require immediate digs, but do require notation and monitoring. Areas with good coating and inadequate cathodic protection also require monitoring. Increasing the cathodic protection current is also recommended. Finally, areas without adequate cathodic protection and damaged coating are of high concern, and should be high priority for remedial action. The survey information found in Figure 11 resulted in a dig at the defect without cathodic protection. A coating defect was found, was due to coating the joint with petrolatum tape instead of the shrink sleeves specified, see Figure 12. Obtaining cathodic protection and coating data, the pipeline operator can prioritize remedial action efficiently and cost effectively.



Figure 12 – Defect found from data in Figure 11

Other factors that affect corrosion prevention can also be added to the survey information. For example, coating defects near AC power lines increase the likelihood of AC current discharge through any defect, concentrating the AC current and leading to AC corrosion. Other areas that may be susceptible to microbiological induced corrosion may require a higher criterion to provide protection.

Combining the surveys provides significant advantages. With both surveys performed at the same time, the surveys are held under the same conditions of soil moisture and temperature. With both sets of data being gathered at the same time by the same instrument, the data is already connected and spatial errors are eliminated. No one needs to sift through thousands of readings to try to line up two surveys to see both the coating and the cathodic protection.

From a financial perspective, performing combined surveys are an advantage. The company is able to obtain information on both methods of corrosion protection at the same time. There is a slight increase in cost to perform a combined survey, but far less than the cost of performing two separate surveys at different times.

As with all surveys, there are some cautions. First, it is vital to ensure that all equipment is synchronized. Utilizing the GPS timing signal is common today with most close interval and DCVG survey instruments. GPS synchronization between current interrupters, survey equipment and stationary data loggers ensures that all readings are taken at the exact same time. Data from stationary loggers can be matched with the survey data to correct for stray current effects by using the time stamp.

The equipment should record the actual data in real time without hardware or software modification. Most impressed current rectifiers produce enough current for the 300 mV shift desired for DCVG. If the rectifiers must be adjusted or additional temporary sources applied, then a CIPS cannot be combined with DCVG. In such cases, it is best to perform the close interval first to ensure there is no change to the polarization. When performing both surveys, utilizing instruments that record the GPS location of the readings is important for data combination later.

CIPS and DCVG surveys can be performed with simple meters or specialized recorders. An example of a simple potential survey is to use a multi-meter to read the potential at a test station. This does give the surveyor an instant indication of the level of cathodic protection. However, the accuracy of this method can be severely affected by the lack of GPS synchronization. Every pipeline can react like a giant capacitor, storing a charge. When the cathodic protection is turned off, there can be an initial inductive spike in the potential of the pipeline that can last for 10 ms to 400 ms. Figure 14 shows the induction spike when the cathodic protection is turned off and on of approximately 100 ms in length. In order to obtain an accurate pipe to soil potential, it is necessary to wait until after the induction spike to read the potential. Modern survey equipment has a programmable reading delay to accommodate this.



Figure 14 – Induction spike

Analogue DCVG involves a surveyor with a sensitive simple meter, similar to Figure 13. One major flaw in utilizing simple meters to read pipeline potentials is record keeping. All simple meters require the surveyor to write accurate notes that are later interpreted and stored. Specialized survey recorders, such as the one shown in Figure 15, store the reading digitally along with date, time, GPS location, notes, etc. and this file can be easily stored and backed up. Another advantage of digital data is that it is easy to combine and compare with other data sets. Information from two or more different types of survey can be compared to see if anomalies are present. Information from different years can be compared to see if there has been any change.



Figure 13 – Analogue DCVG meter

In North America, a process called External Corrosion Direct Assessment (ECDA) is used to ensure pipeline integrity. There are four major steps; pre-assessment, indirect examination, direct examination, post assessment. Pre-assessment involves gathering all relevant information about the pipeline, it's coating, the soil, local conditions, etc. and choosing the best examination tools. This leads to indirect examination where at least two types of survey are performed to evaluate the entire line. Common surveys are close interval potential surveys, voltage gradient surveys, inline inspection or current attenuation surveys. Based on the survey results, the pipeline is evaluated and any anomalies are prioritized for further investigation. Some anomalies lead to the next stage, direct examination. The line is dug to confirm the presence or absence of corrosion and coating defects. After, in the post-assessment phase, the results from all the steps are compiled and compared to ensure that the correct information, survey methods, etc. were used and that the results are valid. ECDA is a continual process where information is gathered and evaluated annually.



Figure 15 – Digital CIPS and DCVG meter

Combining the data from CIPS with voltage gradient surveys allows the engineer to confirm that the coating and cathodic protection systems are both performing correctly. Where one has issues, the other can help to prevent corrosion. Where both have failed, attention and action is required to prevent failure of the unprotected structure. Modern survey techniques allow for accurate surveys, record keeping and multiple data sources to be correlated. Combining CIPS with coating integrity surveys provides the pipeline operator with full knowledge of the corrosion prevention system.

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